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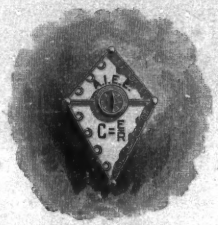
TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.



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RALPH W. POPE, *Secretary*,
26 CORTLANDT STREET, NEW YORK CITY.
Telephone, 2199 Cortlandt.

1896-97.

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Term expires 1897.

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EDWARD WESTON, 1888-9.
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Prof. W. A. ANTHONY, 1890-91
ALEX. GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-93.
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Terms expire 1897.

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[illegible] " " San Francisco, Cal.
[illegible] " " New York, N. Y.

Vol. 1
1896

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Annual Meeting.

New York, May 19th, 1896.

The Annual Meeting of the Institute was held at the New York Industrial Building, corner Lexington Avenue and 43rd Street, May 19th, 1896, and was called to order by President Duncan at 4 P. M.

The President.—The first business in order will be the appointment of two tellers to count the ballots. I will appoint as tellers Mr. Townsend Wolcott and Mr. Wm. J. Hammer.

The next thing in order is the report of the Council and the report of the Treasurer.

The following reports were then read by the Secretary:

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Report of Council for the Year Ending April 30th, 1896.

As required by the Constitution, the Council submits for the information of the membership a report of the work of the Institute during the past year.

The Council has held ten regular meetings and one special meeting, at which the average attendance has been ten. The General Meeting of the Institute was held at Niagara Falls, June 25th to 28th.

In compliance with a request, by petition, of twenty members and associate members, residing on the Pacific Coast, Prof. F. A. C. Perrine has been appointed Local Secretary for that region. In this capacity, Prof. Perrine has rendered efficient assistance in caring for applications for membership received from that district.

Upon his election as a manager, last year, Mr. B. J. Arnold deemed it

advisable to resign the office of Local Honorary Secretary at Chicago and Prof. W. M. Stine was appointed to fill the vacancy.

In compliance with a request from twenty members and associate members, a committee was appointed to submit a new design for a badge which would meet the approval of members and be more generally worn by them. A design has been prepared under the direction of this committee and will be submitted for consideration hereafter.

The amount of time consumed in the counting of the ballots at the annual election led to the appointment of a committee, of which Mr. James Hamblet was Chairman, to revise the rule governing this procedure. The report of this committee was received and referred to the Committee on Incorporations, as other amendments to the Rules were under consideration.

A Committee on Incorporation, of which Mr. W. B. Vansize is chairman, was appointed in December, to consider the incorporation of the INSTITUTE and any changes in the Rules that might be necessary. The whole matter was carefully investigated and the INSTITUTE was accordingly incorporated March 16th, 1896, under the laws of the state of New York. The new Constitution, amended as was necessary in order to conform with the State law, has been printed and distributed to the membership. This action was taken in accordance with the following resolution adopted at the meeting of Council January 22nd 1896:

"It is voted that the President be directed to call a special meeting of "the INSTITUTE to consider a proposition to incorporate the INSTITUTE under "the Membership Corporation Law of the State of New York. (Laws of "1895, Chap. 559, Section 5.)"

This meeting was called for February 26th, at which the Council was authorized by a unanimous vote to proceed with the work of incorporation.

The Council appointed Dr. Francis B. Crocker a delegate to represent the INSTITUTE in the National Conference on Standard Electrical Rules which was held in New York City, March 18th and 19th. This conference resulted in a permanent organization in which the Council subsequently voted to continue the representation of the INSTITUTE for one year, with Dr. Crocker as its delegate.

The National Electrical Exposition Company having extended an invitation to the INSTITUTE to hold its May meetings in the Industrial Building, the proposition was accepted by the Council, and the Secretary was instructed to secure the necessary facilities.

The total membership at the close of last year's report was 944, classified as follows:

Honorary Members		2
Members		281
Associate Members		661
		944
Associate Members elected May 1st, 1895, to April 30th, 1896		143
		1087
Restored to Membership		3
Total		1090

The following resignations have been received during the year, and accepted as in good standing :

J. MURRAY MITCHELL,	J. P. MAGENIS,
F. S. CALDWELL,	C. E. POTTS,
R. L. SELDEN, JR.,	F. G. WATERHOUSE,
M. G. STRATTON,	C. GESSEAUME,
H. H. EUSTIS,	G. W. MANSFIELD,
C. E. STUMP,	F. W. CUSHING,
E. H. ROGERS,	H. HOLLERITH,
B. W. COLLEY,	J. P. McKINSTRY.
J. A. BARRETT,	

Total resignations 17

There have been the following deaths during the year :

FRANKLIN LEONARD POPE,	HOLBROOK CUSHMAN,
HENRY W. FRYE,	W. T. M. MOTTRAM,
WILLIAM BOARDMAN TOREY.	

Total deaths	5
Dropped as delinquents	26
Elections cancelled	3
Elected but not qualified	14
	55
	1035

Leaving a total membership of 1035 on April 30th, 1896, (a net gain of 91) classified as follows :

Honorary Members	9
Members	333
Associate Members	700
	1035

A list of the members elected during the year accompanies this report. The names are printed in the TRANSACTIONS.

The reports of the Secretary and of the Treasurer, show in detail the financial standing of the Institute at the close of the fiscal year, together with a detailed statement of receipts and expenses during the year.

SECRETARY'S BALANCE SHEET.

FOR THE FISCAL YEAR ENDING APRIL 30, 1896.

Dr.		*Cr.*	
To balance from 1894	$ 15 20	By cash to Treasurer	$11,962 90
Receipts for the year	11,267 90	Secretary's Balance on hand	20 20
	11,283 10		11,283 10

ITEMIZED STATEMENT OF RECEIPTS AND EXPENSES OF THE INSTITUTE.

For Fiscal Year Ending April 30, 1896.

General Account.

Receipts.	
Treasurer's Balance from previous year	$186 28
Secretary's " " " "	15 20
Typewriting	8 25
Entrance Fees	660 00
Life Membership (A. E. Kennelly, J. Bijur, R. R. Harvey, J. Stanford Brown)	400 00
Past Dues	694 16
Current Dues	7,903 13
Advance Dues	905 00
Electrotypes Sold	191 21
Transactions Sold	397 76
Transactions Subscribers	175 00
Advertising	144 45
Received for Binding Transactions	33 63
" " Badges	149 08
" " Certificates	58 10
" " Congress-Book	212 13
Reprints Vol. 4	36 00
Total,	$11,469 38

Expenses.	
Repairs	$5 70
Incorporation	11 05
Extra Clerk	5 75
Chicago Meetings	111 00
Library	2 30
Directory	7 50
Ice	8 35
Duties	2 60
Engrossing Resolutions	26 00
Laundry	6 75
Office Expenses	95 53
Office Fixtures	42 60
Express	53 64
Telegrams	4 45
Stenography and Typewriting	987 75
Stationary and Miscellaneous Printing	912 56
Postage	679 33
Messenger Service	5 48
Salary Account	2,499 98
Meeting Expenses	390 39
Rent of Office and Auditorium	1,200 00
Engraving and Electrotyping	655 96
Publishing Transactions	2,972 02
Binding Transactions and Periodicals	280 93
Paid for Badges	165 00
Paid for Certificates	28 85
Congress Book	118 33
Secretary's Balance to next year	90 20
Treasurer's " " " "	239 99
Total,	$11,469 38

The outstanding current bills against the Institute, April 30, amounted to ... $769 13
Due the Institute and collectible probably ... 674 80

Property in New York City according to inventory, May 1, 1896.

Office furniture and fittings	$187 75
Transactions on hand	1,226 00
Congress Books	819 00
Library	200 00
	$2,432 75

Of the above, there has been purchased during the year, office fittings amounting to $25.50. The inventory has been made at a low valuation and does not include the Transactions of 1895.

The indebtedness of $2,511.29 brought over from last year, has been paid, as well as all bills of the current year up to April, being all that were in hand at the last meeting of the Finance Committee, excepting one of $30 held for cause, and another of $208.33 not due until May. The payment of these old bills necessarily carried over, makes an apparent increase in expenses over previous years.

Respectfully submitted for the Council,

RALPH W. POPE,
Secretary.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 19th, 1896.

TREASURER'S REPORT,

FROM MAY 1, 1895, TO MAY 1, 1896.

GEORGE A. HAMILTON, TREASURER, in account with
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Dr.

Balance from May, 1895	$186 28	
Received from Secretary, May 1, 1895 to May 1, 1896	11,962 90	$11,449 18

Cr.

Payments from May 1, 1895 to May 1, 1896, on warrants from Secretary, Nos. 618 to 739, inclusive	$11,209 19	
Balance to new account	239 99	$11,449 18
Balance on hand, General Fund, May 1, 1896		239 99

BUILDING FUND.

Balance as per last report	$850 00	
Interest accrued to May 1, 1896, 3 per cent. to May 14, 1892 and 2 per cent thereafter	89 48	$939 48

Cash book and warrants herewith for audit. Vouchers are in the hands of the Secretary, to whom they are returned for filing after payment.

GEORGE A. HAMILTON,
Treasurer.

New York, May 19th, 1896.

It was voted that the reports be accepted and placed on file.

THE PRESIDENT.—Gentlemen, the counting of the ballots will take so long that I think it would be well to defer the report from the tellers until to-morrow morning. Therefore, I will declare this meeting adjourned until 10 o'clock to-morrow morning.

[Adjourned.]

ASSOCIATE MEMBERS ELECTED AND TRANSFERRED.

Council Meeting, May 19th, 1896.

Name.	Address.	Endorsed by.
HANCHETT, GEO. T.	Editor, with The W. J. Johnston Co., 253 Broadway, N. Y.; residence, Hackensack, N. J.	Townsend Wolcott. W. D. Weaver. Edward Caldwell.
HULL, S. P.	Chief Electrician of Hudson Div. N. Y. C. & H. R. R. Co., Poughkeepsie, N. Y.	T. D. Bunce. J. C. Chamberlain. A. E. Wiener.
LENZ, CHARLES	Draughtsman, Brooklyn Union Gas Co., 187 Nevins Street, Brooklyn, N. Y.	Jos. Wetzler. T. C. Martin. Max Osterberg.

MARTIN, JAMES A.	Superintendent, The E. G. Bernard Co., 43 Fourth Street, Troy, N. Y.	E. G. Bernard. Edward Caldwell. W. D. Weaver.
SCHWABE, WALTER P.	Electrician, Rutherford, Boiling Springs and Carlstadt Electric Co., P. O. Box, 54 Carlstadt, N. J.	Walter M. Petty. Albert Buys. John E. Lloyd.

Total, 5.

APPLICATIONS FOR TRANSFER FROM ASSOCIATE TO FULL MEMBERSHIP. FINAL ACTION.

Approved by Board of Examiners, April 15th, 1896.

ROLLER, JOHN E.	Lieut. U. S. Navy, in charge of Inspection and Installation, U. S. Navy Yard, New York.
EDGAR, CHAS. L.	General Manager and Chief Engineer, Edison Electric Illuminating Co., Boston, Mass.
BREITHAUPT, E. CARL	Electrical Engineer, Berlin, Ont.
SEVER, GEORGE F.	Instructor in Electrical Engineering, Columbia College, New York City.
HARRINGTON, W. E.	Electric Railway Engineer, Camden, N. J.; 1112 Sansom St., Philadelphia.
BEDELL, FREDERICK	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.

Total, 6.

GENERAL MEETING.

MORNING SESSION.

New York, May 20th, 1896.

THE PRESIDENT.—The first business this morning is to listen to a report of the tellers.

The tellers reported, through Mr. Townsend Wolcott, as follows:

REPORT OF TELLERS.

Annual Meeting at New York City, May 19th, 1896.

FOR PRESIDENT.

Total Number of Votes Cast.....330

Dr. Louis Duncan	287	Prof. Edward L. Nichols	2
Dr. F. B. Crocker	28	Charles F. Brush	1
A. E. Kennelly	4	F. J. Sprague	1
Thomas D. Lockwood	3	C. P. Steinmetz	1
Elihu Thomson	3		

Total.....330.

FOR VICE-PRESIDENTS.

Total Votes Cast..... 975

C. P. Steinmetz	307	Elihu Thomson	1
H. J. Ryan	306	T. A. Edison	1
W. M. Stine	267	E. R. Weeks	1
Elisha Gray	10	S. Sheldon	1
Dr. Louis Bell	8	A. L. Rohrer	1
Nikola Tesla	7	O. T. Crosby	1
C. R. Cross	6	E. W. Rice, Jr	1
J. J. Carty	6	W. E. Geyer	1
E. L. Nichols	5	A. V. Abbott	1
A. E. Kennelly	4	Geo. Cutter	1
C. S. Bradley	3	L. B. Stillwell	1
W. J. Jenks	3	H. A. Rowland	1
R. H. Pierce	3	F. W. Darlington	1
W. L. R. Emmet	2	H. S. Carhart	1
F. Bedell	2	P. Lange	1
S. D. Greene	2	W. D. Weaver	1
A. Macfarlane	2	C. O. Mailloux	1
D. C. Jackson	2	H. Ward Leonard	1
Jos. Wetzler	2	A. Schmidt	1
G. S. Dunn	2	W. J. Hammer	1
C. E. Emery	2	Henry Morton	1
C. T. Hutchinson	2	C. D. Haskins	1

Total.....975.

FOR MANAGERS.

Total Vote Cast 1290

L. B. Stillwell	288	W. L. R. Emmet	2
J. W. Lieb, Jr	282	W. E. Geyer	2
F. A. Pickernell	282	C. S. Cornell	2
Wm. L. Puffer	274	J. B. Cahoon	2
E. G. Bernard	14	Louis Bell	2
Samuel Sheldon	12	R. Mc. A. Lloyd	1
Wm. Stanley	12	N. W. Perry	1
Wm. S. Barstow	10	C. D. Crandall	1
A. V. Abbott	7	J. S. Brown	1
A. J. Wurts	7	M. K. Eyre	1
G. S. Dunn	5	H. L. Lufkin	1
S. D. Greene	5	E. A. Sperry	1
A. L. Rohrer	5	A. S. Hibbard	1
G. Wilkes	5	W. J. Jenks	1
F. B. Crocker	4	F. J. Sprague	1
Wm. A. Anthony	3	B. F. Thomas	1
O. T. Crosby	3	F. S. Holmes	1
E. C. Davidson	3	C. R. Agnew	1
F. Bedell	3	E. T. Gilliland	1
S. S. Wheeler	3	C. Cuttriss	1
E. W. Rice, Jr	3	W. S. Aldrich	1
J. Wetzler	3	E. Merritt	1
F. S. Pierson	2	A. C. Crehore	1
E. Caldwell	2	H. V. Hayes	1
R. H. Pierce	2	E. Weston	1
A. Dow	2	F. Reckenzaun	1
C. R. Cross	2	D. C. Jackson	1
Wm. Maver, Jr	2	E. B. Ives	1
F. W. Jones	2	M. I. Pupin	1
C. E. Emery	2	C. J. Field	1
R. B. Owens	2	Nikola Tesla	1
G. D. Shepherdson	2	C. G. Armstrong	1

Total.....1290.

FOR SECRETARY.

Total Votes Cast.....319.

Ralph W. Pope.....319

FOR TREASURER.

Total Votes Cast.....329.

Geo. A. Hamilton	326	W. A. Anthony	1
Ralph W. Pope	2		
Total	329.		

Total number of votes for President (330) indicate total number of ballots counted.

Rejected as not complying with Rules, **28**. In all but one case this was due to the omission of name on outer envelope, in the other case tellers could not interpret marks made upon ballot.

Respectfully submitted,

TOWNSEND WOLCOTT,
WM. J. HAMMER,
Committee.

MR. WOLCOTT.—I would state that there were 28 ballots rejected because they did not comply with the rules. The envelopes containing 27 of these ballots were received without any signature on the outside by which to identify them, and they had to be rejected. The other ballot was marked in such a way that it was impossible for the tellers to ascertain what the voter meant, and that had to be rejected.

Mr. Pope received 319 votes as Secretary, which was the total number of votes cast. For Treasurer there were 329 votes cast, of which Mr. Hamilton received 326. Although there were more votes cast for Treasurer than there were for Secretary, yet the vote for Treasurer was not unanimous. The reason for that is that some members tore off the Council ticket from their ballots, voting the other part, and the name of Mr. Pope was not on that part.

THE PRESIDENT.—The next business is the report of the Sub-Committee on "Standards of Light."

The following report was then read by Dr. Edward L. Nichols:

A Report presented at the 13th General Meeting of the American Institute of Electrical Engineers, New York, May 20th, 1896.

STANDARDS OF LIGHT.

Preliminary Report of the Sub-Committee of the Institute.

BY EDWARD L. NICHOLS, CLAYTON H. SHARP, AND CHARLES P. MATTHEWS.

One of the sub-committees appointed in 1893 to investigate the subject of a suitable standard of light for photometric purposes has been engaged upon preliminary experiments, and upon the collection of data concerning the existing standards, and also of such other sources of light as might be regarded as possible substitutes for the standards now in use. Such investigation is a necessary preparation for the consideration of recommendations looking to the adoption of any new standard.

The committee is still at work upon these preliminary experiments, but it has reached a stage when it seems desirable to make the following report of progress.

I.

The following sources of light have been in use in photometric work for a sufficient length of time to enable various observers to become acquainted with their merits and likewise with their imperfections.

(1) The Carcel Lamp.
(2) The British Standard Candle.
(3) The German Standard Candle (Vereinskerze).
(4) The Methven Screen.
(5) The Hefner-Alteneck Amyl-acetate Lamp.
(6) The Harcourt Pentane Standard.
(7) " " " Lamp.

In addition to these, the Violle platinum standard of light has been before the scientific public for several years, and although it has not gone into extensive practical use, it has been subjected to severe tests in the laboratory of the German Imperial Institute for Research (Reichsanstalt in Charlottenburg) and elsewhere. Various luminous gas flames, also incandescent lamps, have been extensively used as secondary standards. The following standards have likewise been proposed, and a certain amount of work has been done to demonstrate their good properties and to determine the degree of accuracy with which they can be reproduced.

(1) The crater of the positive carbon in the arc.

(2) The surface of a strip of platinum heated by means of a current to an arbitrarily defined temperature.

Finally there are a number of light sources which must be taken into account in the selection of a standard of light, aside from those which have been mentioned in the above list. Such are gas flames burning within a mantle of pure oxygen (The Bude Light), the acetylene flame, the various incandescent mantle burners, the light from other glowing metallic oxides, such as the zircon light and the light of burning magnesium.

The committee proposes to present in this report a summary of measurements which have been made upon the various sources of light mentioned above, with a view to reaching some decision with reference to their relative merits as light standards. It is hoped thus to pave the way for experiments leading to the recommendation of new definitions of the standard of light, or at least to the recommendation of greatly improved procedure in the handling of existing standards.

In the case of many of these sources of light, the members of the committee have made extensive measurements of their own, either in the verification of existing statements, or in the exploration of questions hitherto not definitely attacked. It is proposed in this report to give a brief resumé of these experiments, some of the results of which have already appeared elsewhere, and to summarize the existing work of previous investigators, so far as the committee is acquainted with the same.

II.

Tests of standards of light belong to one of two general classes; in the first class are included all comparisons of flames with flames, the results of the tests being in this case affected by

the change of the standard flame with the purity, temperature, and hygrometric state of the atmosphere. They show in general only the variations of the standard in question which take place during short periods of time, and demonstrate nothing concerning the variations which take place from day to day. In the second class are included all comparisons of light standards with glow lamps and also bolometer tests.

Tests of British Standard Candles.

The British standard candles were specified by act of Parliament, in 1860, to be sperm candles weighing six to the pound, and burning 120 grains per hour. In spite of universal condemnation by all who have tested this standard, it still maintains its position in Great Britain and America.

Messrs. Harcourt, Keats and Methven, appointed by a committee of the Board of Trade to investigate the performance of British candles, found a difference of 15 per cent. in the average illuminating power of legal candles, while two pairs showed a maximum variation of 22.7 per cent.

Heisch and Hartley, acting for the committee on light standards of the Council of the Gas Institute, found that the differences in the illuminating power of candles ranged from 1.3 per cent. to 16 per cent., the average difference being 7.05 per cent. They also reached the conclusion that sperm candles developed more light per grain of sperm consumed, than they had done several years before.

Dibdin conducted two long series of experiments with various standards, reporting the results of the tests to the Metropolitan Board of Works. He compared the standards with the flame produced by a specially stored coal-gas. His tests were very extensive, and his reports voluminous and exhaustive. For the British candle he found in his first series of tests a maximum variation of 14.9 per cent., which occurred twice, and a maximum total variation in a single group of 23.2 per cent. which also occurred twice. The mean variation, disregarding signs, was 3.6 per cent. Variations of from five to eight per cent. were common; 13.7 per cent. of the tests were within one per cent. of the mean. In the second series the maximum variation was 11.7 per cent., and the maximum total for one group 19.3 per cent. The mean variation was smaller on account of the fewer observations in each group. This may account for the

fact that in this series 34 per cent. were within one per cent. of the mean.

In his next report he combats the view of Heisch and Hartley that candles gave more light per grain of sperm then, than they had given several years before. Comparing determinations of the candle power of the Carcel lamp made in 1870 with others made in 1879, he found that the illuminating power of candles had decreased rather than increased during these nine years.

A committee of the British Association, comprising numerous distinguished members of that body, in their fourth report rendered at the Plymouth meeting in 1888, gave the results of extensive tests of candles. Their comparison standard was a burner supplied with coal-gas which had been enriched with pentane. Of 118 experiments, 98 gave differences of one per cent. from the mean, 57 gave differences of two per cent., 19 of five per cent. while differences of nine per cent. to ten per cent. were produced only very irregularly. They concluded that candles are not worthy to be called standards, although they conform to the legal requirements, and that the intensity of their light is affected by the purity of the air in the room, the shape and construction of the wick, the nature of the sperm and by other causes.

They also pointed out that the spermaceti is not a substance of definite chemical composition; that improvements in the process of manufacturing have resulted in what is known as a "dryer" sperm, one containing less oil; that to prevent crystallization, a variable quantity of beeswax is added. They inferred from these considerations that it is probably true that the illuminating power of candles has changed since the quality of sperm employed, the construction of the wick with respect to the number of strands, the tightness of the twist, etc., are not specified in the act, but are left to the option of the makers. This committee regarded as the chief source of the oscillations of the light:

(1) Changes in the length and shape of the wick.

(2) Difference in the height of the melted sperm in the cup of the candle.

Photometric observations by the many other observers have simply served to confirm the above conclusions. A recent

Dutch commission, for example[1], found, from many tests, the mean fluctuation in the intensity of British standard candles to be ± 2.43 per cent., with a maximum of 9.70 per cent.

Methven has shown the following variations in the intensity of a candle to take place with changes in the azimuth of the plane of the wick. Two candles were used, their intensities being as follows:

Plane of the wicks perpendicular to bar, C. P. = 1.999.

Wicks pointing away from the photometer, C. P. = 1.933.

Wicks pointing towards the photometer, C. P. = 1.957.

He found also that a candle which gave in dry air an intensity of 1.104 gave in moist air an intensity of 1.196,—a variation of 8.38 per cent.[2]

III.

Bolometric Measurement.[3]

The extraordinary fluctuations of such sources as the British candle make photometric measurements difficult and uncertain. The consideration of the discrepancies exhibited in the results of previous observers suggested to the members of your committee the substitution of the bolometer for the eye, in the study of such sources of light. The following is a summary of the investigation which resulted from this suggestion.

Description of Apparatus.

A piece of Swedish iron wire, of No. 30 B. & S. gauge, was passed through jeweler's rollers until its thickness was about 0.045 mm. and its width 1.5 mm. It was then placed in dilute sulphuric acid, in which potassium bichromate had been dissolved, and a current was passed through it in such a manner as to dissolve the iron. The potassium bichromate was introduced into the solution to dispose of the hydrogen bubbles which would ordinarily have clung to the metallic surface, and which would have caused it to be dissolved unevenly.

1. For an abstract by Krüss, see *Journal für Gas Beleuchtung und Wasserversorgung* (1894).

2. John Methven: *Dingler's Polytechnisches Journal*, vol. 277, p. 276, taken from London *Gas World*, 1889, p. 572. See also Sugg: *Journal for Gas Lighting*, which is reprinted in the *Scientific American Supplement*, No. 484, p. 7726.

3. For a more detailed description of these measurements, see Sharp and Turnbull, *Physical Review*, vol. ii, p. 1.

In this way the strip was obtained which was about 0.025 mm. in thickness and still moderately strong. From this strip were cut two pieces, each about 6 cm. in length, to constitute two arms of a Wheatstone bridge.

To carry the strips so obtained, a light oblong frame, *F* (Fig. 1), of thin wood was made, and to it were fastened small bits of sheet brass, *b*, *b*, *b*, to which the strips and the copper wires intended to connect them with the other arms of the bridge could be soldered. The strips, *S*, *S'*, were then bent and placed over the frame, so that each strip crossed the frame twice. The free ends of each strip were displaced laterally from each other, so that, when viewed from the front, the portion of the strip on one side of the frame hid only very little of the portion on the other side of the frame.

After the two strips had been arranged on the frame sym-

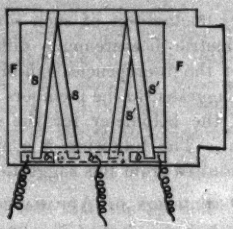

FIG. 1.

metrically with respect to each other, the one which was to receive radiation was carefully smoked on both sides. To accomplish this smoking without undue heating of the strip, a piece of sheet metal, through which a small hole had been punched, was held over a candle flame so that the flame was caused to smoke. The smoke passed through the hole, over which a tube was held to direct the current. The strip was passed back and forth over the top of the tube. In this way a very delicate strip can be blackened without injury. In their completed state, the strips had a resistance of about 0.5 ohm each.

The frame holding the strips was mounted in a wooden box about 20 cm. long and 5 cm. × 6 cm. in cross-section. A number of suitable cardboard screens were placed in the front portion of the box to shield one of the strips from radiation and to protect both of them from draughts. To close the box at its

other end a piece of bright tin was cut equal in size to the cross-section of the box. This was soldered fast to a heavy block of brass, to the other end of which was soldered another piece of tin which covered the end of the box. When this arrangement was placed in the box, the first piece of tin came close behind the bolometer strips, and its bright surface acted as a mirror in reflecting upon the back of the exposed strips many rays which would otherwise have been lost.

By this means the efficiency of the bolometer was nearly doubled. The tinned surface did not tarnish perceptibly during the course of the investigation. It was not smooth enough to reflect a distinct image, and the light reflected from it was to a large extent scattered. The use of a plane-surfaced mirror in such a position would not be allowable, since any slight change in the angle of incidence would cause a different amount of light to be reflected upon the bolometer strip. The use of the irregular-surfaced plate, since it diffuses the light, can scarcely affect the accuracy of the results to an appreciable degree in such work as has been done with this bolometer. Nevertheless, this arrangement is to be recommended only where great sensitiveness is desired rather than the most exact comparison of results.

The galvanometer employed was of the four-coil type. It was constructed by Professor W. S. Franklin, after the same general plan as has been followed by Snow,[1] Paschen,[2] and others. When the two front coils were in multiple with each other and the two rear coils similarly connected, and the two pairs were connected in series, the resistance was found to be 190 ohms. The moving parts consisted of four little magnets of piano wire, each about 5 mm. long, and a mirror of thin cover glass, 4 mm. wide by 7 mm. long, all mounted on a slender rod of glass and suspended by a very fine quartz fiber. Any oscillations of the needles were very strongly and effectively damped by the air resistance to the light-moving parts—a very essential condition to the correct operation of the instrument when used to get the variations of a rapidly fluctuating source of radiant energy.

The scale was divided into 100 half-inch divisions, each of

1. B. W. Snow, "Wied. Ann.," Vol. 47, p. 213; *Phys. Review*, Vol. 1, p. 2.

2. F. Paschen, "Wied. Ann.," Vol. 48, p. 272; *Zeitschr. für Instrumentenkunde*, Vol. 13, 1893, p. 13.

3. Ångström, "Oefvers. af kongl. Vetenskaps-Akad. Förhandl.," 1888, Vol. 6, p. 379.

which was, in turn, divided into tenths. The distance of the scale from the galvanometer was 100 scale divisions, *i. e.* 50 inches. With the telescope used, fifths of the smallest divisions could be estimated. In speaking of scale divisions, the half-inch divisions will always be meant.

To test the sensitiveness of the apparatus, the galvanometer was adjusted until the period of the needles was six seconds for a complete vibration. A deflection of one scale division corresponded to a current of 68×10^{-10} amperes.

This deflection of one scale-division corresponded to a temperature rise in the bolometer strips of 0°.00657 C. If we reduce this to millimeter divisions on a scale placed at a distance of 1 m. from the mirror, we see that one millimeter deflection corresponded to a current of 68×10^{-11} amperes, and the corresponding rise in temperature of the strip was 0°.00066 C.

This temperature sensitiveness is much smaller than has usually been employed in bolometer work, but it was amply sufficient for the purpose. That the bolometer itself was one of high sensitiveness is evident from the fact that this degree of sensitiveness was attained with galvanometer needles swinging in a strengthened field and with a galvanometer of 190 ohms resistance. The conditions for maximum sensitiveness of the bridge would have required a galvanometer resistance of only 0.5 ohm.

The reason for the great sensitiveness lay in the nature of the strips employed. Their area was considerable, the temperature coefficient of the iron was high, and the current through it was large, ranging from 0.15 to 0.20 ampere, the size of the strips permitting the use of a large current without undue heating. As a result of the strong field in which the galvanometer needles swung, the drift due to magnetic changes was usually imperceptible.

The bolometer, compensating resistance, and battery were all placed in an interior room, with thick brick walls, and having communication with the outer room only by a door, *D*, Fig. 2.

The temperature of this room changed very slowly, and it was quite free from drafts. The bolometer box, *B*, was placed upon a shelf fastened to the door of the room, and looked out through a hole in the door upon the outer room. A double screen, *S*, of tin, arranged to slide up and down on the outside of this door, covered up the bolometer strips when desired. The box *B'*, containing the compensating resistance, was also fastened

to the inside of the door. The end of the box through which the screw projected, fitted into a hole in the door, so that the screw would be turned and the bridge balanced from the outer room.

In getting the variations of candles, a special device was required to keep the top of the burning candle at constant height in front of the bolometer strip. A suggestion of Mr. C. H. Bierbaum, M. E., resulted in the construction of the following simple and effective arrangement. A spiral spring, about 60 cm. long and 4 cm. in diameter, was attached to a small scale-pan,

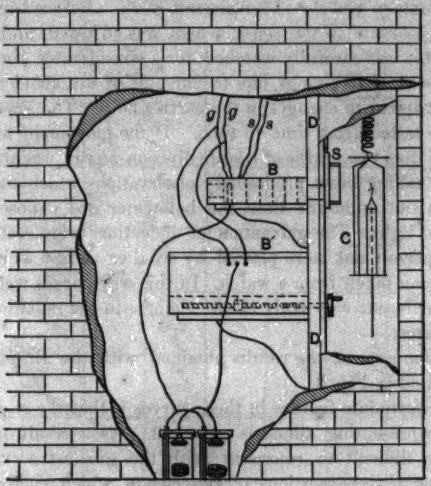

FIG. 2.

and the spring was cut off to such a length that when a candle was put on the scale-pan, the elongation was just equal to the length of the candle. The spring would then take up as fast as the top of the candle was lowered by burning. A small piece of sheet metal served to protect the spring from the heat of the candle. In order to keep the scale-pan from swinging sidewise and from oscillating up and down, a couple of wires were passed vertically through holes on opposite sides of it, and served as loosely fitting guides, which, without interfering with the take-up of the spring, effectually damped any vibrations. The ad-

justment of a spring to any candle could be made in a few minutes with sufficient accuracy so that the height of the top of a candle burning on the scale-pan would not vary over 1 mm. in an hour. *C*, Fig. 2, shows this arrangement in place.

Method of Taking Observations.

All determinations of the variations of standards were made at times when the laboratory and its surroundings were very quiet. Most of them were made between the hours of seven and twelve in the evening; a few were made on holidays, when the laboratory was closed for general work. Before beginning a set of observations the sensitiveness was adjusted, and the galvanometer was carefully watched for a considerable time to get the amount of its swings due to currents of air about the bolometer strips or to changes in the earth's field. The sensitiveness was also tested from time to time. If the movement amounted to more than two tenths of a scale division no run was attempted.

After taking these preliminary observations which usually required about an hour's time, the bolometer was exposed to the source of light. The galvanometer deflections were read rapidly by one person and were plotted by another as fast as read, the times being taken from a watch. In this way curves were traced which represent very truly all the changes in the radiation of the light source.

The character of the results obtained with the British candle is exhibited in Fig. 3.

An unfortunate feature in these curves is that the scale of abscissas, representing times, is so small. As a result of this, it has been difficult to represent with the greatest accuracy the true slope of those portions of the curves which correspond to very rapid changes in radiation. In examining the curve, it should be borne in mind that a very steep line may cover several seconds of time, and that it is quite possible that a photometric setting might be made during the time that a candle is executing just such a variation as is represented by the steepest parts of one of the candle curves. The number of galvanometer readings plotted during the space of five minutes was usually from 50 to 100.

At the end of a run, the strips and surrounding parts were given time completely to lose the heat imparted to them, after which readings for zero and sensitiveness were taken. The

Fig. 3.

curves were corrected for changes in zero and in sensitiveness, using the equation:—

$$\frac{\text{change in sensitiveness}}{\text{initial sensitiveness}} \times \text{approximate mean ordinate} = \text{correction to ordinate.}$$

It has been impossible to draw the curves so as to show clearly the minor fluctuations due to minute changes in the intensity of the radiation, since, as has been said, the scale to which the time abscissas are plotted is very small, compared with the scale of ordinates. These important peculiarities of the movements of the galvanometer needle were clearly perceptible, however, to one who observed the galvanometer deflections for only a litte time, while their character made it perfectly evident that the swings of the galvanometer needles in their natural period exercised only an inappreciable influence on the slopes of the curves and the magnitudes of the variations recorded.

TABLE I.

BOLOMETRIC MEASUREMENS OF THE BRITISH CANDLE.

(DATA FOR CORRECTIONS OF THE CURVES.)

Number of curve.	Times of taking zero and sensitiveness readings.	Time of lighting.	Time of taking the curve.	Hourly rate of consumption.	Distance from bolometer.	Initial sensitiveness.	Correction for		Reduction to standard		
							Drift.	Change of sensitiveness.	Sensitiveness.	Distance.	Rate.
	h. m. h. m.	h. m.	h. m. h. m.	grams	cm.						
I.	8 47 and 10 01	8 50	8 50 10 9 35	7.910	25.3	26.2	+0.9	+0.2	0	−2.3	−0.70
II.	9 41 10 50	9 33	9 50 10 35	7.767	26.0	26.1	−0.4	0	+0.3	0	+0.05
III.	8 50 9 15	8 00	8 00 9 00	7.842	26.0	26.1	−2.9	+0.8	+0.3	0	−0.34
III. (a)	9 38 10 30	8 00	9 45 10 15	7.842	26.0	26.08	+0.3	0	+0.3	0	−0.34
IV.	7 50 9 05	7 50	7 50 8 50	7.692	25.3	26.15	+1.0	−0.1	+0.1	−2.1	+0.45
IV. (a)	9 35 10 30	7 50	9 45 10 15	7.692	25.3	26.4	−0.1	0	−0.5	−2.3	+0.45

In Fig. 3, and in subsequent cuts containing bolometric curves, the smallest divisions of abscissas represent five minutes of time. The corresponding divisions of ordinates are five divisions of the galvanometer scale. In order to economize space, no attention has been given to the height of the curves relative to the base line on the plates. The total ordinates for each curve are indicated by such a symbol as this $\left.\begin{matrix} \text{I} \\ \text{II} \end{matrix}\right\}$ 40, indicat-

ing that the true X-axis for curves I. and II. should be placed ten divisions below the base line on the plate. Consequently, on the various plates, curves having the same ordinates are plotted one above the other, the true ordinate being indicated in the way mentioned above.

The data by which the curves have been corrected are given in Table I.

Table II. gives, in its first column, the approximate abscissas of the portion of the curve in question, and in its second column the mean ordinates of these portions. The third column contains the deviations of the mean ordinates of the portions from the mean ordinate of the whole curve. The fourth column contains these deviations reduced to percentages of the whole. The fifth contains similar deviations from the mean ordinate of all the curves of the particular standard under consideration, and in the sixth these also are reduced to percentages.

Discussion of the Results Obtained with British Candles.

Fig. 3 shows the curves given by the English standard candles. In curves III. and IV. the candles were lighted at their tops. The wicks flared up and gave a high point on each curve, which in the case of curve IV. is not shown on the plate. The flames then increased gradually to their normal size, which was reached after about 15 minutes. Curves III. (*a*) and IV. (*a*) are continuations of III. and IV. The candles were allowed to burn during the interval between the curves, which in the case of III. and III. (*a*) was 45 minutes, and in the case of IV. and IV. (*a*) was 55 minutes. During III. the room was rather more draughty than during III. (*a*), and the effect of the draughts is seen in the much larger numbers of small irregularities in the former than in the latter curve. During the interval between IV. and IV. (*a*) the height of the flame of the candle was found to vary between 43 and 48 mm.

Curve I. was taken with the portion of candle left over from IV. and IV. (*a*). It was lighted, its wick being already charred and its crater formed, and readings were taken immediately. Curve II. was taken with the lower half of the candle used in getting III. and III. (*a*). The bottom, *i. e.* the larger end of this, was hollowed out to expose the wick, and readings were taken after the candle had been burning long enough to come to its normal light-giving power. The agreement in the amount of

TABLE II.

RESULTS OF BOLOMETRIC MEASUREMENTS (BRITISH CANDLE).

	Time: Minutes on curve.	Mean ordinates and their mean.	Deviations from the mean ordinate of the curve.	Deviations reduced to percentages.	Deviations from mean ordinate of all the English candle curves.	Deviations from general mean reduced to percentages
Curve I.	15–20	41.68	−10.4	−2.43	+0.59	+1.44
	20–25	44.68	+1.96	+4.58	+3.59	+8.72
	25–30	40.84	−1 88	−4.40	−0.25	−0.61
	30–35	43.39	+0.67	+1.57	+2.30	+5.59
	35–40	43.71	+0.99	+2.32	+2.62	+6.37
	40–45	42.04	−0.68	−1.59	+0.95	+2.31
		42.72	Correction for rate of burning = −0.70.			
Curve II.	45–50	39.24	−1.77	−4.32	−1.85	−4.50
	50–55	37.85	−3.16	−7.70	−3 24	−7.87
	55–60	39.12	−1.89	−4.61	−1.97	−4.79
	60–65	40.44	−0.57	−1.39	−0.65	−1.48
	65–70	40.76	−0.25	−0.61	−0.33	−0.80
	70–75	42.85	+1.84	+4.48	+1.76	+4 28
	75–80	43 52	+2.51	+6 12	+2.43	+5 92
	80–85	43.20	+2.19	+5.34	+2.11	+5.13
	85–90	42.11	+1.10	+2.68	+1.02	+2.48
		41 01	Correction for rate of burning = +0.05.			
Curve III.	15–20	43.04	−0.54	−1.25	+1 95	+4.74
	20–25	42.88	−0.70	−1.62	+1.79	+4.35
	25–30	42.82	−0.76	−1.76	+1.73	+4.21
	30–35	42.18	−1.40	−3.23	+1.09	+2.65
	35–40	43.23	−0.35	−0.80	+2.14	+5.20
	40–45	44.80	+1.22	+2.80	+3.71	+9.02
	45–50	43.58	0	0	+2.49	+6.06
	50–55	44.30	+0.72	+1.65	+3 21	+7.80
	55–60	45.38	+1.80	+4.13	+4.29	+10.45
		43.58	Correction for rate of burning = −0.34.			
Curve III. (a).	60–65	43 25	+0.83	+0.53	+2.16	+5.25
	65–70	43.52	+0.50	+1.16	+2.43	+5.91
	70–75	42.82	−0.20	−0.47	+1.73	+4.21
	75–80	43.68	+0.66	+1.54	+2.59	+6.30
	80–85	42.82	−0.20	−0.47	+1 73	+4.21
	85–90	42 04	−0.98	−2.28	+0.95	+2.31
		43.02	Correction for rare of burning = −0.34.			
Curve IV.	15 20	38.65	+1.42	+3.89	−2.44	−5.94
	20–25	39.84	+2.61	+7 01	−1.25	−3.04
	25–30	38 07	+0.84	+2.26	−3.02	−7.35
	30 -5	35.76	−1.47	−3.87	−5.33	−12.95
	35–40	35.72	−1.51	−4.05	−5.37	−13.08
	40–45	37.44	−0.19	−0.51	−4.05	−9.84
	45–50	35.84	−1.39	−3.75	−5.25	−12.78
	50–55	37.16	−0.07	−0.02	−3.93	−9.55
	55–60	36.96	−0.27	−0.72	−4.13	−10.05
		37.23	Correction for rate of burning = +0.45.			
Curve IV. (a).	60–65	38.26	−1 47	−3.70	−2.83	−6.88
	65–70	39.04	−0.69	−1.74	−2 05	−4.99
	70–75	38 26	−1.47	−3.70	−2.83	−6.88
	75–80	40.84	+1.11	+2.80	−0.25	−0.62
	80–85	40.84	+1.11	+2.80	−0.25	−0.62
	85–09	41.16	+1.43	+3.60	+0.07	+0.17
		39.73	Correction for rate of burning = +0.45.			

Mean ordinate of all the English candle curves is 41.09.
Mean ordinate of all the English candle curves corrected for rate of burning is 41.05.
Mean ordinate of all the English candle curves corrected for rate and reduced to true deflections is 41.06.

radiation of the candle burned in this way, with the amount when burned from the smaller end, shows that the variation in the diameter of the candle has little if any influence on the intensity of the light emitted.

One marked peculiarity which characterizes, to a greater or less degree, all these curves, is the succession of sudden drops followed by gradual rises to a maximum. In the case of the drop in curve IV. at 55 minutes, the change amounted to 15 per cent. of the total deflection, and in other instances the change was nearly or quite as large. The reason for these drops is to be looked for in the action of the wick, which, as the candle burns down projects farther above the spermaceti, causing a tall flame. Finally, by reason of charring and because of its own weight, it bends over and the ends burns off. The flame following the wick becomes shorter.

Since the wicks of English standard candles are very uniform in construction, these drops succeeded each other after nearly regular time intervals of about three minutes.

A confirmation of these results, together with conclusive evidence of the legitimacy of the bolometric method of studying light sources will be found in section IV. of this report.

IV.

The study of the irregularities exhibited by the British candle suggested to one of the members of your committee that the use of a different criterion of the light emitted by a candle than that now employed, namely, rate of consumption of sperm, might lead to better results in their use. The method proposed is to measure at the time that the photometric setting is made, the height of the flame. Then knowing the relation between flame—height and intensity of light emitted, to reduce the instantaneous intensity to intensity at standard height.

Two methods were employed to determine the ratio of the flame height to the intensity. In the first method the intensity of the radiation of the candle was measured by the bolometer in the way previously described. To measure the height of the flame, a long camera was constructed, having its lens and ground-glass plate at a fixed distance from each other. The ground-glass plate was graduated empirically to read directly in millimeters the height of objects focussed upon it. The candle was placed on a pan attached to a spiral spring of such a length that

its elongation would be just equal to the length of the candle. By this arrangement the top of the candle was kept at a constant height above the floor, and when once the image of the base of the flame had been accurately adjusted on one of the lines of the camera screen (to facilitate which the screen was capable of a slight vertical movement), it remained there during a considerable period of time. Hence, to measure the height of the flame at any instant, it was necessary only to glance at the image of the *top* of the flame and to note its position on the screen.

The magnifying power employed was about two, and heights were measured only to 0.5 mm. Greater closeness of measurement was deemed unnecessary on account of the ill-defined nature of the base and tip of the flame. The actual base of a candle flame is difficult to observe, on account of the small quantity of light which it emits. The procedure adopted was to set on the line of demarkation between the charred and uncharred portions of the wick, since this was found usually to mark the base of the flame. In case a close inspection of the candle showed the base of the flame to be slightly above this point, a further adjustment of the screen was made.

In order to insure great steadiness of the flame, the candle was placed in a roomy, well ventilated box having a glass window. Having put the candle in position before the bolometer, and having adjusted the camera properly, the bolometer screen was raised, and simultaneous observations were made of galvanometer deflections and flame heights. These readings were corrected for any change in sensitiveness of the bolometer and any drift of the galvanometer needle, and were plotted, using flame heights and galvanometer deflections as co-ordinates.

In the second method, a Lummer-Brodhun photometer was used. At one end of a photometer bar 200 in. long was placed a 110-volt glow lamp. This was maintained at a voltage of 100 by means of a storage battery. Being run at a low efficiency, its color was about the same as that of a candle, and its change in candle power during the time it was in use was too small to be detected.

At the other end of the bar was the candle, supported by its adjusted spring. The candle was always placed so that the curl

of the wick was perpendicular to the axis of the bar.[1] The arrangement for measuring flame heights is shown in Fig. 4, which represents a projection of the apparatus on a horizontal plane. *B* is the photometer bar, *C* the candle, *M* a mirror placed behind the candle in such a way as to reflect the rays from it through the lens *L*, which projected them on a graduated screen, *S*, placed immediately behind the bar. The mirror was carried on a movable support, so as to admit of an adjustment of focus.

This arrangement was adopted, since by its use one observer could do all the work. The method was simply to make a rather quick photometer setting, and then instantly to note the position of the top of the flame on the screen, reading the position of the photometer afterwards.

The observations were treated in the following manner: The various observed values of flame height were collected in such a way that heights of 41.0 mm., and 41.5 mm., and 42.0 mm.,

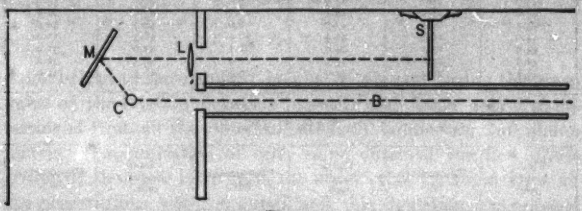

FIG. 4.

formed one group; 42.5 mm., 43.0 mm., and 43.5 mm., another, etc. The mean height of each group was found, and also the mean bar-reading corresponding to it. The candle power of the standard was found by taking the mean of all the heights and bar-readings, and reducing, by means of an approximate correction, to a standard height flame of 45 mm. Using this value for the intensity of the glow lamp, the intensity of the candle corresponding to each group was computed. By means of a curve plotted from these values, the percentage variation per millimeter of flame height was determined.

In order to find the relative accuracy of this, and of the ordi-

1. For the variation of the intensity of candle as a function of the azimuth of the plane of the wick, see Methven, London *Gas World*, 1889, p. 572.; also an article by Sugg, in the *Journal for Gas Lighting*, which is reprinted in the *Scientific American Supplement*, No. 484, p. 7726.

nary method of using candles, the following observations were made: A candle burning normally was weighed by the "method of transits," was transferred to the spring balance, and ten or more photometer settings made—the flame height also

TABLE III.

Flame height, mm.	Galvanometer deflection.	Flame height, mm.	Galvanometer deflection.	Flame height, mm.	Galvanometer deflection.
48.0	29.0	44.0	26.7	43.0	25.8
48.5	29.5	45.0	27.3	44.0	27.0
49.5	30.3	45.5	28.3	Wick of candle cleaned.	
48.0	29.2	43.5	27.0		
47.0	28.2	43.5	27.0	55.0	37.2
47.5	28.8	44.5	27.5	46.5	30.6
45.5	27.5	44.5	27.5	47.5	31.3
46.5	28.0	45.0	28.3	48.0	32.0
46.5	28.2	44.5	27.7	49.0	32.7
46.5	28.0	43.5	26.5	49.0	32.6
45.0	27.0	43.5	27.0	49.5	32.8
45.5	27.6	43.0	26.5	50.5	33.7
45.5	27.8	42.5	26.0	50.0	33.0
44.5	26.5	43.5	26.8	50.0	33.0
42.0	25.8	42.5	25.5	50.0	33.2
43.0	26.5	43.5	26.0	49.0	32.6
43.0	26.0	44.0	26.3	47.0	30.4
43.5	26.7	43.5	26.0	48.5	30.0
44.0	26.8	43.5	26.2	48.5	31.0
44.5	27.1	44.0	26.7	47.0	31.0
44.5	27.2	44.5	27.0	46.5	31.0
43.5	26.4	44.0	26.8	46.5	31.0

TABLE IV.

Flame height, mm.	Photometer bar.	Flame height, mm.	Photometer bar.	Flame height, mm.	Photometer bar.
45.5	702	41.5	712	53.0	686
46.5	699	43.0	707	48.0	700
48.0	700	43.0	708	48.5	695
49.0	693	44.0	706	46.0	704
51.5	690	44.0	707	45.0	708
53.0	697	45.0	705	44.0	707
44.5	700	44.0	709	44.0	711
46.0	705	44.0	710	46.0	707
49.0	694	43.0	713	43.0	713
46.0	699	45.0	708	46.0	708
48.0	698	End of wick cut off.		44.5	710
48.0	693			44.0	711
49.0	691	40.0	719	45.0	711
45.5	700	44.0	708	45.5	708
44.0	707	47.0	698	46.0	712
45.5	699	48.0	696	42.5	716
48.0	697	50.0	693	42.0	715
46.0	698	54.0	688	43.0	715
46.5	696	53.0	688	44.0	714
45.0	700	51.0	693	45.0	711
45.0	702	50.0	694		

being noted. The candle was then weighed again, and another group taken. A number of such sets of observations were made on several days, and since the glow lamp was used as a reference standard, these sets are comparable with each other.

The mean value of the candle power of the glow lamp given by each of these sets of observations was corrected for rate in the ordinary way, and also corrected by reducing from the mean

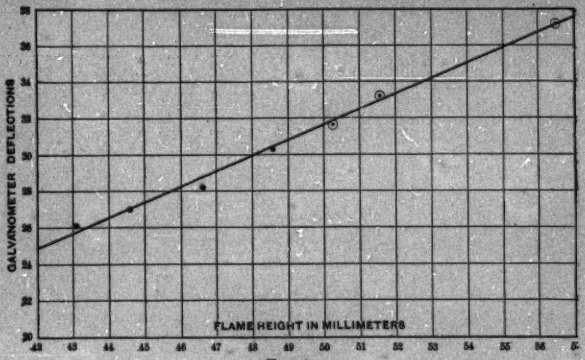

FIG. 5.

flame height to the standard height of 45 mm., using the mean value of the relation between intensity and flame height as determined from all the observations, both bolometric and photometric. The deviation of each value obtained for the candle power of the glow lamp from the mean value obtained from all the observations was computed, and this deviation was reduced to percentages. A comparison of the percentage deviations given by the two methods shows their relative accuracy, while the absolute values of the percentages show the error which one is liable to make in using candles in either of the two ways.

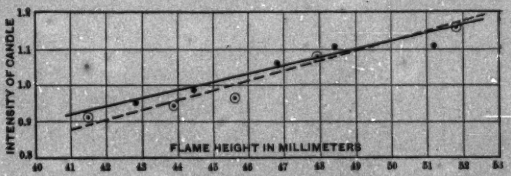

FIG. 6.

Table III. gives a characteristic set of data obtained by the use of the bolometer, 1894, March 21. Table IV. is a similar set of photometric data obtained 1895, November 6. The data of

Table III. and Table IV. are shown reduced and plotted in Fig. 5 and Fig. 6 respectively. Table V. gives values found for the variation in intensity of candles expressed in percentages per milli-

TABLE V.

Bolometric.	Per cent.	Photometric.	Per cent.	Photometric.	Per cent.
1894. Nov. 29	2.2	1895. July 27	3.3	1895. Dec. 3 E	
Dec. 5	2.7	Oct. 30	3.4	G	2.3
1895. Feb. 23, I.	2.2	Nov. 1 I.	3.3	H	
II.	2.5	II.	3.3	Dec. 4 I	
III.	3.2	Nov. 6 I.	2.2	J	
March 21, I.	3.1	II.	2.7	K	2.6
II.		Nov. 27 I.	2.7	L	
Oct. 4	2.7	II.	2.9	M	
		Dec. 2 A.M., A	2.7	N	
		B			
		Dec. 2 P.M., C			
		D	2.8		
		D'			
Mean	2.7			Weight mean of all	2.7

TABLE VI.

Name of group of observations.	Rate.	Flame height.	C. P. of glow lamp uncorrected.	C. P. corrected for rate.	C. P. corrected for flame height	Deviation from mean corrected for rate.	Deviation from mean corrected for height.	Percentage deviation. Rate.	Percentage deviation. Height.
								o/o	o/o
A	7.601	43.0	6.11	5.99	5.78	+ 0.35	+ 0.04	+ 6.0	+ 0.7
B	8.320	45.15	5.785	6.20	5.80	+ 0.56	+ 0.06	+ 9.8	+ 1.0
C	6.981	44.95	6.01	5.41	6.00	- 0.23	+ 0.26	- 4.25	+ 4.3
D	8.100	46.1	6.09	6.35	6.25	+ 0.71	+ 0.51	+12.6	+ 8.7
E	7.157	46.4	5.58	5.09	5.73	- 0.55	- 0.01	- 9.8	- 0.2
F	7.863	44.7	5.67	5.74	5.62	+ 0.10	- 0.12	+ 1.6	- 2.1
G	8.030	44.8	5.72	5.91	5.69	+ 0.27	- 0.05	+ 4.8	- 0.9
H	7.330	44.05	5.80	5.47	5.66	+ 0.17	- 0.08	+ 3.0	- 1.4
I	8.422	44.3	5.65	6.13	5.54	+ 0.49	- 0.20	+ 8.5	- 3.5
J	7.271	47.1	5.33	5.02	5.65	- 0.62	- 0.09	-11.0	- 1.6
K	7.367	46.15	5.50	5.22	5.67	- 0.42	- 0.07	- 7.6	- 1.2
L	7.440	45.6	5.64	5.41	5.73	- 0.23	- 0.01	- 4.25	- 0.2
M	7.137	42.3	6.00	5.52	5.50	+ 0.19	+ 0.18	+ 3.3	+ 3.2
N	7.301	44.2	5.79	5.45	5.67	- 0.19	- 0.07	- 3.5	- 1.2
Means, disregarding signs....	7.594	44.9	5.76	5.64	5.74	0.36	0.125	6.35	2.16
Nov. 6, I.		45.5	5.60		5.68		- 0.09		- 1.6
II.		45.3	5.79		6.00		+ 0.23		+ 4.0
Nov. 11		43.1	6.17		5.85		- 0.08		- 1.4
Nov. 12, I.		44.1	5.87		5.73		- 0.04		- 0.7
II.		42.9	6.20		5.85		- 0.08		- 1.4
Dec. 2, D'		49.3	5.36		5.99		+ 0.22		+ 3.8
Means of all, disregarding signs.....		45.0	5.78		5.77	Last six only.	0.123		2.14

meter. Table IV. shows, in the way described above, the comparative accuracy of the two methods of reducing candle observations. Fig. 7 shows plots obtained from groups of observa-

tions designated by *A*, *B*, *C*, . . . *N*. Fig. 8 shows plots from three successive sets of bolometric observations.

An inspection of the tables and curves will show that while

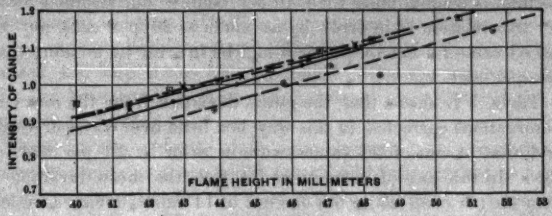

FIG. 7.

the relation between flame height and intensity is a fairly definite one for any given group of observations, there is a considerable range of variation in the values for it as obtained from different groups. Moreover, the relation sometimes changes during one burning of the candle. Fig. 8 illustrates this peculiarity in, that there is a group of points marked ⊡ which lie considerably below the line plotted to represent all the observations; and that

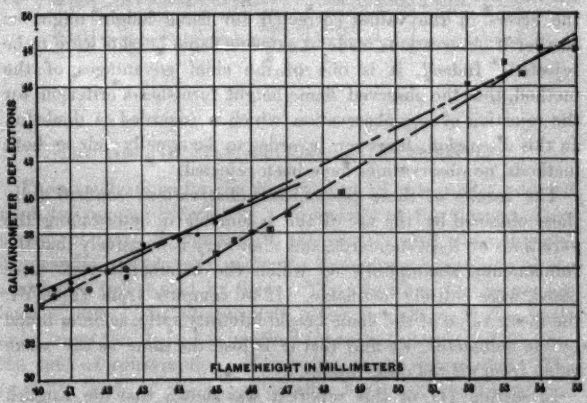

FIG. 8.

the slope of the flame height-intensity curve plotted from the points marked ⊡ is materially different from that obtained from other groups of points. This may be due to a change in

the shape of the wick. The fact that this relation is not absolutely constant does not vitiate the proposed method of treating candle observations; for since the deviations of flame height from 45 mm. is seldom more than 10 per cent. if our assumed value for this relation is in error by as much as 20 per cent. our reduced value for candle power would be in error by no more than two per cent.

Table VI. shows that the mean deviation from the mean of observations corrected in this way is a little over two per cent., and that 14 out of 20 values were in error by 2.1 per cent. or less. In the case of corrections for rate, the mean deviation is over six per cent. while but one out of 14 values deviated by less than two per cent. and only four by less than four per cent.

In other words, by correcting for flame height an error of less than two per cent. may reasonably be expected, and the probability of making an error greater than four per cent. is small; while in correcting for rate, errors of eight per cent. and nine per cent. are of common occurrence.

The values corrected for rate might, perhaps, be more consistent if the rule were followed to reject all observations in which the rate fell below 114 or above 126 grains per hour. Similarly, the errors in the values corrected for flame height might be smaller if observations made at extreme flame heights were to be rejected. Indeed, it is one of the chief advantages of the method, that the observed flame height furnishes a criterion for the rejection of any observation which is regarded as doubtful. In this discussion, however, in order to be equally fair to both methods, no observations have been rejected.

The results of these photometer observations confirm fully those obtained by the use of the bolometer in determining the variations of light standards, and show very conclusively that the fundamental assumptions on which the bolometric tests were based, were entirely justifiable. If we compute from Table VI. the mean value of the flame height-intensity ratio, as determined by the bolometer, we find that it is just the same as the mean value from *all* the observations.

In section III. of this report it was shown that the English candle is subject to sudden variations in intensity which are sometimes as large as 15 per cent. Many of these sudden drops were noticed while making the photometer observations, and they all had the same characteristics as are shown by the bolometer

curves. Fig. 9 shows a group of these observations—group F in the tables. Assuming that the time intervals between the various photometer settings were equal, points were plotted showing the relation between intensity of the candle and time, and between flame height and time. It will be seen at once that the two curves are of very similar characters. The flame height gradually increased, and with it the intensity, until, when the height of 48 mm. had been reached, there was a sudden drop, the change in intensity amounting to 12 per cent.

These curves evidently show in an imperfect way variations precisely similar to those which are so faithfully reproduced by the galvanometer needle. In view of these qualitative and quantitative results, it would seem to be impossible to doubt the reliability of the bolometer as an instrument for making such tests.

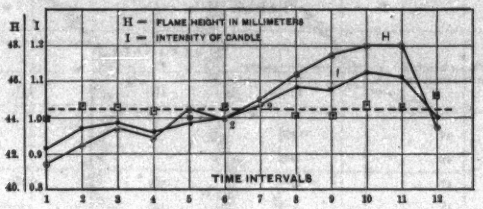

FIG 9.

V.

THE GERMAN STANDARD CANDLE (VEREINSKERZE).

The specifications for the manufacture of this candle, adopted upon the recommendation of a committee of the German Association of Gas Manufacturers, are very careful and complete. The candle is made only under the immediate supervision of the association and is sold by them. The directions for its use are most minute. The photometric measurements are to be made only when the flame has reached its normal height, of 50 mm., the rate of consumption of paraffin being disregarded. The candle is made of the purest paraffin, has a uniform diameter of 20 mm. the number of strands of wick, also, being carefully specified. In the earliest recommendations for the use of this candle it was directed that the candle be allowed to burn freely, and when the flame height had reached 50 mm. then the photo-

metric settings were to be made. In later years, however, the recommendation was made that the wick of the candle be cleaned or snuffed in order to insure the reaching of the standard flame height more quickly. The use of this candle as an official standard has been abandoned even in Germany in favor of the Hefner lamp, and, consequently, it is not necessary to deal very extensively with tests which have been made of it.

Lummer and Brodhun[1] in determining the intensity of the Hefner light in terms of the German candle, using glow lamps as intermediate standards, investigated the performance of the candle with a good deal of care. Measuring the height of the flame by means of a cathotometer, they experienced difficulty in seeing the exact point of termination of the base of the flame, and also from the fact that the top would split up into three

TABLE VII.

Flame heights in millimeters.	Intensity.		
	I.	II.	III.
44	0.398		
45	.405		
47	.410	.389	0.380
48	.419	.398	.390
49	.425	.405	.396
50	.434	.410	.398

points, and when the height was near the normal height, the flame would smoke. Their measurements show that the ratio between flame height and intensity with this candle is not a fixed one.

At one time the height remained at 50 mm. for some minutes, and the following settings were made: 0.412, 0.420, 0.420, 0.424, 0.430. During this time the edges of the crater melted off to some degree.

Bolometer tests[2] of this standard were made by members of the present committee. They do not, however, show its behavior when used under normal conditions. They indicate a more uniform performance, except for continual small variations than is

1. Lummer and Brodhun: *Zeitschr. für Instrumentenkunde*, vol., 10, p. 119.
2. Sharp and Trumbull, *Phys. Rev.*, vol. ii, p. 1.

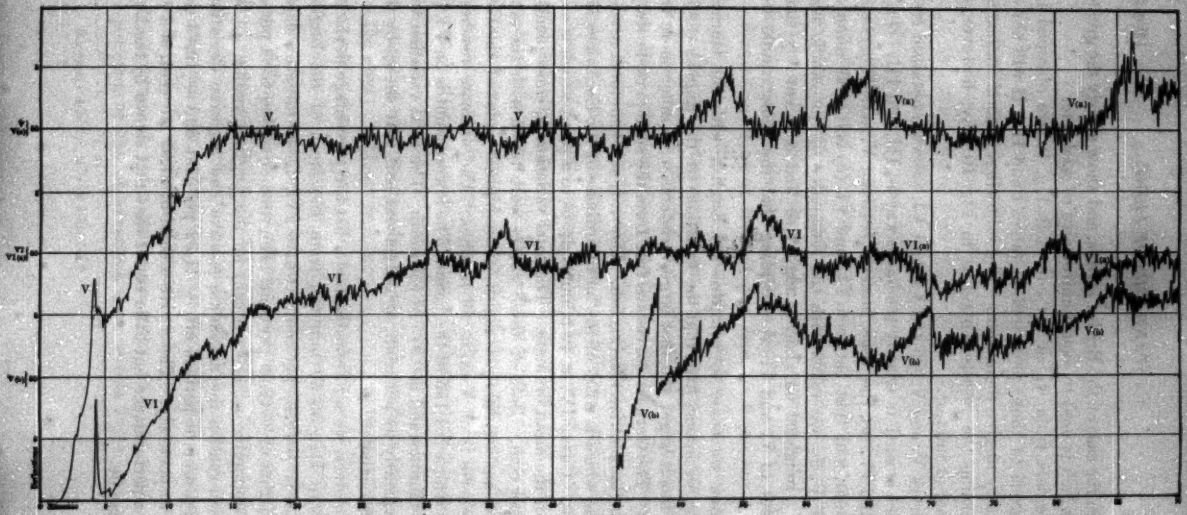

FIG. 10.—The German Candle.

seen in the case of the British candle, and show clearly the greater care which is used to secure uniformity of wick, etc.

The data from which the curves in Fig. 10 are obtained are analogous to those presented in tables I and II. It will not be necessary to give them here. The following general statements concerning the results embodied in Fig. 10 may, however, be deemed of interest.

Curves V. and V. (*a*) and VI. and VI. (*a*) were obtained from candles burned in exactly the same way as III. and III. (*a*) and IV. and IV. (*a*), the time interval between V. and V. (*a*) being one hour, and that between VI. and VI. (*a*) being 41 minutes. Curve V. (*b*) was taken with the remainder of the candle used for V., relighted on another night; so that it is entirely independent of V. and V. (*a*) excepting that the same candle was used.

When we come to compare the English with the German candle, we notice, first, that the variations of the English candle were much larger and that large variations were much more frequent. The German curves are free from the semi-periodic drops which characterize the English. Curve I. at 24 minutes reaches a value which is 1.255 of the mean ordinate of the English candle curves. Curve IV. at 49 minutes drops to a point which is only 0.77 of the mean ordinate. The total variation is, consequently, 46.5 per cent. Both of these curves were taken with the same candle, but on different nights. The highest point of the German curves is on V (*a*) at 86 minutes. The ordinate reaches a value which is 1.155 of the mean. The lowest point is on VI. (*a*) at 72 minutes, and is 0.915 of the mean. The total variation was consequently 24 per cent., or only about half that shown by the English candle.

Moreover, we see from the table that the percentage deviation of curve III., 55–60 minutes, from the mean of the English candles is + 10.45 per cent. Curve IV., 35–40 minutes, shows a deviation of — 13.08 per cent. The total deviation for a period of five minutes is 23.53 per cent for the English candles. In the German candles the maximum positive and negative deviations for five-minute periods are + 11.52 per cent and — 10.43 per cent. respectively. These give a total of 21.95 per cent. and exhibit a performance but little better than that shown by the English candle.

VI.

The Methven Screen.

Dibdin's results of tests of this standard are even less significant of what the standard will do from day to day under varying conditions, than are his tests of candles, because here he compared two gas flames with each other, and they must have been similarly affected by varying atmospheric conditions. He found in his observations, which are given in his report of 1885, for determinations made by one operator, a maximum fluctuation of 5 per cent., frequent fluctuations of from 2 per cent. to 3 per cent., while 37 per cent. of the measurements were within 1 per cent. of the mean of all. From observations by three different operators, the maximum was found to be 6.7; many of the fluctuations were of from 3 per cent. to 6 per cent., while 12.5 per cent. of the observations were within 1 per cent. of the mean. Using the carburetted gas, a result perhaps slightly better than the above was obtained, but with gas of varying purity he found large errors entering when the gas was bad. For example, a flame giving 18.50 candle power when compared with the Methven burning 16-candle gas, gave when 10-candle gas was used in the Methven 31.30 candle power, indicated in one test, and 22 candle power indicated in another. This shows clearly that the variation of candle power with the Methven is not a definite function of the richness of the gas, especially if the gas is poor. Dibdin's observations in this respect have been confirmed by the work of Rawson.[1] His conclusion is in contradiction to that of Heisch and Hartley, who found no variation whatever when the standard was supplied with gas running from 13.65 candle to 22.4 candle. Dibdin says: "These results . . . . must seriously militate against the adoption of the plain gas Methven slit standard, however useful it may be as a handy instrument in ordinary works. The arrangement for carburetting is, on the other hand, a very different thing and capable of very reliable work." In his other report, he says, "Observations with different operators cannot be considered as very satisfactory, for generally more experience with the carburetted gas is required than would appear necessary." In this second report, he found for the deviations, using carburetted gas, a maximum value of 5 per cent., while 74 per cent. of the observations were within 1 per cent. of the

1. Rawson: Electr., 17, p. 479, 1886.

mean. He found also that bad results were obtained if the burner and chimney had not had time to become thoroughly warm before use. By using several chimneys of varying thicknesses, he found no serious error resulting from this cause.

Rawson[1] found in investigating this standard, that it was difficult to determine just when the flame height was three inches on account of the flickering of the flame. He found also changes in the rate of flow of gas when the eye could hardly detect any change in flame height. His observations show that the light emitted varies rapidly with changes in the quality of the gas when the gas is bad to start with. This is confirmed also by the work of the Dutch Commissioners, who found for the candle power of the Methven standard, using 15-candle gas, 2.05 candle power, while for 18-candle gas the candle power was 2.23.

Methven[2] has discussed the effects of changes in temperature and pressure, on this standard. The effect of increased pressure

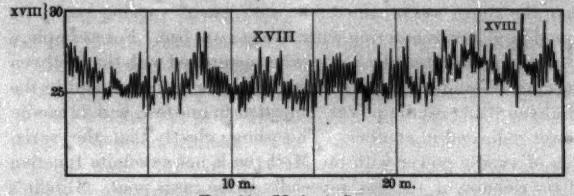

FIG. 11.—Methven Screen.

and temperature is not to increase the size of the flame on account of more rapid flow of gas, but in burning denser gas in a denser atmosphere the size is diminished. With lower pressure and higher temperature the density of the flame is less, and the draught of the chimney is less. Less oxygen flows, and the flame takes on a brownish color. If the specific gravity of the gas is low, the intensity is much increased; if high, the increase is less marked. The draught is determined by the difference between the temperature of the room and of the flame, and hence for equal quantities of gas, and varying room temperatures the intensity will be different. A given gas gave 15.93 C. P. at 3°, 9 *C;* and 16.90 C. P. at 22°, 2. This accords with the results of M. Bremond, who found for a given gas at different elevations

1. Rawson, loc. cit.
2. Methven: *Dingler's Polytechnishes Journal*, vol. 277, p. 276, 1890.

above the sea-level a decrease in intensity of 0.742 per cent. per 100 feet increase in elevation. Moreover, the intensity is 10 per cent. less when the flame burns in moist air than when the air is dry. Coal-gas burning in a Harcourt burner shows under similar circumstances a diminution of 13 per cent.

Fig. 11 and 12 exhibit specimens of the bolometric curves obtained by your committee in the case of the Methven screen. Curve XVIII. was taken with the Argand burner connected directly to the gas-pipes in the building. The pressure of the gas was controlled only by a large regulator on the main pipe leading into the building. The consumption of gas in the building was constant during the run. The curve shows many large, but quick, variations and certain decided waves. The other Methven curve was taken with a gas-holder of about 10 gallons' capacity interposed between the gas main and the Argand burner. The effect of this in smoothing the curves is very marked, and indicates

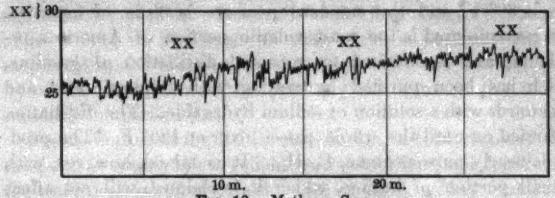

FIG. 12.—Methven Screen.

that for photometric purposes the Methven screen is much improved by the interposition of a rather capacious reservoir. The use of such a reservoir tends to minimize the effect of changes of pressure and to absorb any waves in the gas due to water in the pipes or some similar cause.

The way in which these waves of variable pressure produce fluctuations in the amount of radiation, is by causing changes in the quality of those portions of the flame which cover the slit. At times the top of the flame becomes forked, so that not all of the slit is covered by it. It happens perhaps more frequently that some of the non-luminous portion of the flame rises so as partially to cover the slit. In either case the result is seen in a deviation of the curve. It must be true, also, that the amount of luminous radiation suffers a much larger proportional change than the total amount of radiation; hence the deviations recorded

on the curves are too small to represent correctly the fluctuations in luminous intensity. There is an additional reason for these fluctuations, which is to be found in the slight protection against draughts of air which the wide open chimney used on the London Argand burner affords. In this respect its action is in marked contrast with that of the smaller close chimney of the Carcel lamp, which, of course, can be used only with much richer gases than ordinary illuminating gas.

VII.

A. Vernon Harcourt's Pentane Standard.

This standard[1] consists of a gas flame produced in burning a mixture of 20 volumes air with 7 volumes of pentane vapor. The flame is $2\frac{5}{16}$ in. height, the orifice through which the gas passes being $\frac{1}{4}''$ in diameter. The rate of consumption of the gas is $\frac{1}{2}$ cu. ft. per hour. The standard temperature for making the mixture is 60° F., and the standard pressure is 30 in. of mercury. The pentane used is the most volatile portion of American petroleum, and is obtained by repeated distillation of gasoline, which has been purified by treating with sulphuric acid, and afterwards with a solution of sodium hydroxide. The distillation is carried on until the whole passes over at 120° F. The product is nearly pure pentane, C_5 H_{12}. It is mixed, however, with a small portion of hexane, which, it is claimed, will not affect the illuminating power of the gas, since it is so similar in chemical composition to pentane. The pentane evaporates more quickly than ether, and is nearly insoluble in water. Its specific gravity at 60° F. is between 0.628 and 0.631; its vapor is 2.5 times as heavy as air. The flame produced is said to be steady when the gas is rich and the flame not too large, while an additional advantage consists in the fact that the rate of consumption of gas at a given flame height furnishes a check upon the purity of the gas.

Dibdin, in his tests made in 1885, used an apparatus set up by Harcourt himself. He found that when the air gas was made over fresh water in the gas holder, his results did not agree exactly with those obtained when the water had been previously used for the same purpose. The size of the holder, and the exact

1. A. Vernon Harcourt, Report of the proceedings of the British Association, 1877. *Chemical News*, 36, 108. *Electrician*, 11, 188.

purity of the gas seemed to have no effect upon the candle power given. From his measurements, the maximum fluctuations were found to be 1.9 per cent., while 90 per cent. of the measurements lay within 1 per cent. of the mean. Five different operators, using the same burner, made measurements which were not so concordant. Their maximum deviation was 3.5 per cent., while only 44 per cent. fell within 1 per cent. of the mean. Dibdin found the steadiness of the flame to be affected but little by disturbances in the room, etc. This is quite opposed to the results of Heisch and Hartley, who had found that small disturbances in the neighborhood caused very considerable and very troublesome fluctuations in the size of the flame.

Dibdin's report of 1888 shows the maximum variation to have been over 5 per cent., and 80 per cent. within 1 per cent. of the mean. He says: "The facts brought out by the inquiry have shown that the method of preparing the air-gas is at once easy and safe; that the measurement of the volume of gas used is simple and reliable; that the adjustment of the flame height is a matter of certainty; its steadiness all that could be desired when due care is taken and proper apparatus employed; and that the quality of the light afforded is precisely the same as that of the standard comparison flame."

The committee of the British Association, in 1888, reported that the pentane standard was reliable and convenient, and fulfilled all the conditions required of a standard of light. They found that the light was not altered by using pentane of specific gravity of 0.628 or 0.632 instead of the normal specific gravity 0.630. Out of 117 tests which they made, only one showed a variation of one per cent., and there were no larger variations than that.

VIII.

The Pentane Lamp.

(Woodhouse and Rawson pattern.)

In the pentane lamp we have a flame of pentane vapor set free from a wick, and burning inside a metal chimney cut away in the middle. The height of the flame is adjusted by noticing when the point of it plays inside the limits of a vertical slit in the upper part of the chimney. The distance between the upper and lower parts of the chimney determines the intensity of the light. It can be adjusted to give one candle or one-and-a-half candles.

Dibdin, in his report in 1888, states it to be remarkably steady. The maximum fluctuation which he found was 2.5 per cent. while 97 per cent. of the tests fell within 1 per cent. of the mean.

The committee of the British Association in 1888 reported that out of 118 tests but two showed fluctuations of 1 per cent., which was a maximum.

Rawson[1] compared the pentane lamp with the glow lamp on a photometer bar. He found for the pentane lamp absolute steadiness for periods of from 15 to 75 minutes. Variations were due to two causes:

(1) The charges of temperature in the air of the room, which can be minimized by immersing the lamp-font up to the stopper in water.

(2) The escape of pentane vapor through the stopper. This may be prevented by placing a drop of glycerine on the stopper.

Mr. C. H. Clifford of the Massachusetts Institute of Technol-

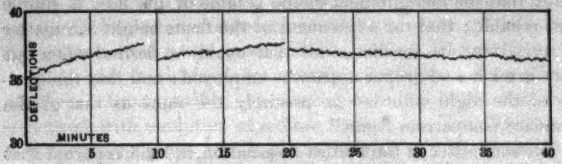

FIG. 13.—Harcourt Pentane Lamp.

ology[2] compared two pentane lamps with each other and found a maximum deviation of 1.57 per cent., while five out of 18 observations varied by more than 1 per cent. from the mean. He says: "The Harcourt pentane lamp as a legal standard would seem to be a satisfactory one as far as mere intensity and constancy of illumination are concerned, although the uncertain quality of pentane and the care required in using the lamp are undoubtedly objectionable."

But a single reliable curve Fig. 13 has been obtained by the bolometer for this standard. The great steadiness of the flame due to the chimney employed is manifest at once. This form of chimney evidently is quite as efficient in this respect as is the Carcel lamp chimney and it is not subject to the disadvantages of the latter form.

1. *Elec. World*, London, vol. xii., p. 251.
2. *Tech. Quarterly*, 1890.

The lamp was adjusted to give 1 C. P. and had been burning 1½ hours before the curve was begun. During the first nine minutes of the curve the height of the flame changed, remaining, however, always within the limits of the vertical slit. The intensity changed during these nine minutes by 6.7 per cent. of itself. The flame was then readjusted. During the next nine-and-a-half minutes a similar change took place, the total variation being 2.9 per cent. After a second readjustment the flame settled down to a fairly stable condition. The flame height was a trifle low at the end of the curve, at which time the intensity had fallen to a minimum value of 1.4 per cent. below the mean. At the end of the second ten minutes the intensity was 1.4 per cent above the mean. Omitting the values at the beginning of the curve, which may perhaps not be quite so reliable as the rest, the total variation is seen to be 2.8 per cent. The changes produced in the two readjustments were 3.2 per cent. and 1.4 per cent. respectively. Of course, from this single curve nothing can be said concerning the reproductibility of the standard. The bolometer shows the intensity of this lamp to be less than 1 C. P., and photometric measurements have confirmed this result.

Weighty objections to this lamp as a standard are the unstability of the flame under certain conditions, and the lack of a well-defined mark at which the flame height can be adjusted. It is to these faults that the variations during the first twenty minutes of the curve are due.

Liebenthal[1] investigated the relation between the height of the flame and intensity of the light, finding the following values: For the flame point at the bottom of the slit the intensity was 97.9; for the flame point one-third of the way up the slit, 99.5; one-half of the way, 100; two-thirds of the way, 99.5; at the top, 97.5.

Accordingly he adjusted it at the middle of the slit, taking that flame height as corresponding to normal intensity. He says: "Still greater variations of flame height produce changes which are not negligible, even for technical purposes. The intensity is about eight per cent. less than normal when the point of the flame projects by a small amount (about seven mm.) over the top of the slit, and a further decrease of at least seven per cent. is found when the flame becomes still larger. More than this, on account of the heating of the parts of the lamp, until a certain

1. Liebenthal, *Elektrotechnische Zeitschrift*, vol. xvi., p. 655.

thermal equilibrium is reached, which is about 30 min. after lighting, two things occur:—

(1). The flame increases continually so that the wick must be steadily lowered.

(2). The intensity increases and finally goes over into a constant value which is several per cent. larger than the original value. Only when such a stationary condition has been reached, and the flame height changes but gradually, can one leave the lamp unwatched for a little while without fearing that it may become overheated."

By making many photometric measurements, extending over a long time, using a glow-lamp as a secondary standard, and by determining each day the hygrometric state of the air, by means of an Assmann's hygrometer, Liebenthal investigated the effect upon the intensity of the light which the moisture in the air exerted. From 75 observations of this sort the intensity of the Harcourt lamp in terms of the Hefner light as unit can be expressed by the following equation:

$$y = 1.232 - 0.0068\ x,$$

or

$$y = 1.232\ (1 - 0.0055\ x),$$

where y represents the intensity, x the watery vapor in liters to each cubic metre of dry air, free from carbon dioxide. This formula holds good between the limits of observation which were from 4 to 18 liters, and gives us a variation of about 0.6 per cent. per liter of moisture. The mean deviation of observed intensities from those computed from the equation was found to be 0.81 per cent., and the maximum deviation was 1.6 per cent.

By making observations under varying pressure in a physician's pneumatic cabinet, the following relation between intensity and barometric height was obtained.

$$\Delta\ y = 0.00049\ (b - 760),$$

where b represents the barometric height in millimeters.

Hence, to a change in barometric hight of 40 mm. corresponds a change in intensity of two per cent.

The Dutch Light Standard Commission found the Woodhouse and Rawson pattern of the Harcourt lamp to be the most promising form of light standard. They objected to the use of pentane, as not being of definite chemical composition, and a modified form of lamp was arranged to burn a mixture of 100 parts of ethyl ether and nine parts benzol. Their lamp reproduces all

of the essential features of the Harcourt lamp. One important modification is that they make the chimney and upper portion of the wick tube detachable. This can be placed on a base by which illuminating gas can be admitted, lighted and burned until all these parts of the lamp have reached a stationary temperature. The chimney and wick tube are then replaced upon the font, and upon lighting, the lamp is ready to be used in photometric measurements. The materials which are burned in the lamp can readily be obtained in a pure state, and are not excessively expensive. They found that for slight changes in the amount of benzol added, when the proportions recommended were approximated to, the intensity of the lamp varied very slowly. Two series of ten settings each of two of these lamps against each other showed a variation of $\pm$ 0.52 per cent, while their intensities were equal. The maximum variation was $\pm$ 2.10 per cent.

IX.

Hefner Lamp.

Herr von Hefner-Alteneck[1] was led to the construction of the lamp which bears his name, as the result of his experiments upon simple benzine lamps. These lamps had round flames and large chimneys. With them he found excellent photometric results, using different grades of benzine as combustibles. He pointed out and insisted upon the necessity for using a combustible of known chemical composition. Accordingly an investigation was made of the intensity of the flames given by five fuels of different chemical composition, including among them commercial amylacetate. These showed only insignificant differences in intensity as long as the flames were adjusted to equal heights. He concluded from this that the height of the flame is the significant factor in defining intensities.

As a result of this experiment, he proposed the following lamp for giving a light of unit intensity. From a metal base projects a wick tube of German silver, 8 mm. in interior diameter, 0.15 mm. thick, and 25 mm. high. The flame height is adjusted at 40 mm. by the use of a "sight," or a Krüss's optical flame measure. The wick fills the tube without being compressed, and is arranged so that its height can be adjusted with nicety. Since the combustible, amylacetate, $C_7H_{14}O_2$, volatilizes at a low tem-

1. *Elektrotechnische Zeitschrift*, vol. iii., p. 445, and vol. v., p. 20.

perature, the wick does not need to be brought up to the top of the tube and does not char. The lamp should be burnt at least ten minutes before being used for photometric purposes.

The results of his investigation of the effect of impurities in the amylacetate are shown in the following table :[1]

TABLE VIII.

Amylacetate diluted with	Specific gravity.	Hourly consumption in grams.	Deviation from normal rate.	Deviation from normal intensity.
			Per cent.	Per cent.
20 per cent. fusel oil.....	0.8645	9.96	+ 6.9	— 2.6
2 per cent. diamylen.....	0.8725	9.24	— 0.8	0
5 per cent. alcohol and 4 per cent. castor oil.....	0.8745	9.88	+ 6.0	Impossible to measure.
10 per cent. isobutylacetate and 10 per cent. amylalcohol	0.869	9.28	— 0.4	+ 0.4
50 per cent. alcohol	0.8408	12.92	+39.	+40.
Pure	0.8735	9 318		

His conclusions were that variations in intensity due to the impurities which are most common are unnoticeable, while large variations from the normal are detectible through a change in the rate of consumption. Thus the rate furnishes a check both on the purity of the material and the intensity of the light.

Liebenthal[2] found that an increase or decrease in the diameter of the wick tube by 1 mm. caused a diminution of 1 per cent. in the intensity. Hence the given diameter corresponds to a maximum intensity. On the other hand, 1 mm. change in the height of the wick tube produced a corresponding change in intensity of only 0.2 per cent.

He investigated also the relation between flame height and the intensity of the light emitted. Measuring the flame heights by a cathetometer, he found the mean error to be 0.08 mm. to 0.09 mm. Using the ordinary "sight," the mean error was 0.5 mm., which may increase to 1 mm. if the eye is fatigued. This is due to the disturbing influences of the non-luminous mantle about the point of the flame. From this cause large errors may enter. With Krüss's optical flame measure, the mean error was 0.3 mm., which corresponds to an error of 0.9 per cent. in intensity.

1. von Hefner-Alteneck: *Elektrotechnische Zeitschrift*, vol. xxv., p. 323.

2. *Elektrotechnische Zeitschrift*, viii, p. 504, and ix, p. 96, taken from *Journal für Gasbeleuchtung und Wasserversorgung*.

The mean variation of flame height during several periods of time was the subject of another part of his investigations. His results were as follows :—

Between the 12th and 23d of October, the mean variation of the flame height of a lamp, A, was 0.32 mm.

Between October 24th and 29th the mean variation of A was 0.19 mm., and of B 0.035 mm. Between October 30th and November 30th the mean variation was 0.16 mm. for both A and B.

Finally he found that the intensity of the Hefner light could be expressed, with a sufficient degree of accuracy, as a linear function of the flame height. For heights less than 40 mm.,

TABLE IX.

	Lamp H 11, mean Intensity.	Deviation from mean.	Percentage Deviation.	Mean Error of each group.
			Per cent.	Per cent.
	0.3521	− 0.26	− 0.73	± 0.35
	58	+ 0.11	+ 0.31	.38
	53	+ 0.06	+ 0.17	.23
	30	− 0.17	− 0.48	.44
	53	+ 0.06	+ 0.17	.32
	56	+ 0.09	+ 0.25	.44
	62	+ 0.15	+ 0.42	.60
	26	− 0.21	− 0.59	.54
	63	+ 0.16	+ 0.43	.27
Means.....	0.3547		± 0.40	± 0.40

this is represented by the first of the following equations; for heights greater than 40 mm., by the second :—

$$i = 1 + 0.025\ (h - 40).$$
$$i = 1 - 0.034\ (40 - h).$$

The exact relation which he found is shown in Fig. 14.

Investigations for the purpose of determining the value of the illuminating power of the German standard candle, in terms of the Hefner light, Lummer and Brodhun[1] compared four Hefner lamps with a glow lamp. They obtained data in Table IX, concerning one of the lamps. These results show what degree of accuracy can be expected of this standard. From the intensity

1. *Zeitschrift für Instrumentenkunde*, vol ix, p. 119, 1890.

as given by them, the deviation of each set of measurements from the mean intensity has been computed, and this deviation has been reduced to percentages.

The intensities of the other lamps were as follows:

Lamp H_I { 0.3545 / 0.3569 } Lamp H_{III} { 0.3539 / 0.3558 } Lamp H_{IV} { 0.3468 / 0.3455 / 0.3452

Mean intensity of H_I, H_{II} and H_{III} was 0.3547.

Mean error was $\pm$ 0.13 per cent.

The deviation of the intensity of H_{IV} from the mean of the other was 3 per cent. The inner diameter of the wick-tube of H_{IV} was 8.22 mm., and hence the deviation of its intensity from the mean of the others confirms Liebenthal's observation as noted above.

The conclusions which were reached as a result of the official tests of the Hefner lamp at the Reichsanstalt, are as follows:[1]

"Investigations have shown on the whole a favorable result. The intensity is not dependent upon dimensions of the lamp in such measure as to demand too much of the maker; the thickness of the walls of the wick tube is of importance, since if they are too thick the intensity is lessened, while if they are too thin the flame no longer burns steadily. A degree of purity of the combustible which the chemist cannot easily reach is unnecessary, while impurities can be detected by simple tests. Less favorable is the dependence of the intensity upon the surrounding air, the presence of carbon dioxide having a strong influence. For the setting of the height of the flame either the "sight" or the optical measure may be used; whichever is used, it should be adjustable."

Liebenthal[2] investigated the variations in intensity of the Hefner light as dependent upon hygrometric state, pressure, and amount of carbon dioxide in the atmosphere. The method in which this investigation was carried out has already been indicated in our discussion of the Harcourt lamp. He took a series of observations extending through 12 consecutive months, of the intensity of the Hefner light as compared with a glow lamp, measuring each day the hygrometric state.

The glow lamp had previously been used for a long series of tests of many Hefner lamps and so its intensity in terms of that

1. *Zeitschrift für Instrumentenkunde*, vol. xiii., p. 257.
2. *Elektrotechnische Zeitschrift*, vol. xvi., p. 655.

unit was well known. From the table which is given, it can be seen "that the Hefner lamp in March, April and May, also in Oct. and Nov. had an intensity almost equal to 1, while during the months of June to Sept. its intensity was on the average 2 per cent. smaller, and in the months of Dec. Jan. and Feb. it was larger by about the same amount. To be sure, the variations in the single months are not insignificant. For the month of May for example, the variation was in the neighborhood of five per cent. The least intensity, 0.948, occurred in July, and the greatest, 1.033; in Jan. and Feb. moreover the variation of the light intensity during the year under consideration amounted to 8.5 per cent."

"Further, it is to be noticed that during this year the mean deviation of the intensity from that obtained from the previous calibration of the glow lamp was $\pm$ 1.78 per cent."

"The graphical representation as well as the computation by the method of least squares shows that the intensity, y, of the Hefner lamp can be represented with great accuracy as a linear function of the moisture of the air, x. We have, between the investigated values of hygrometric state of from three to 18 liters,

$$y = 1.049 - 0.0055\,x,$$

or

$$y = 1.049\,(1 - 0.0053\,x).$$

"The intensity decreases uniformly with increasing moisture by an amount equal to 0.55 per cent. per liter. The difference between the observed variations in intensity and those computed from the equation, is at its maximum 0.9 per cent. while its mean value is $\pm$ 0.41 per cent. In the original definition of the light unit the moisture of the air was not taken into consideration. Since the deviations which follow from this are in the mean $\pm$ 1.78 per cent. the original definition of the Hefner light is sufficient for almost all technical purposes. If one wishes a greater accuracy, some datum concerning the hygrometric state of the air must be inserted in the definition of the light unit. It would be necessary then to determine for what proportion of moisture the intensity of the Hefner lamp should be taken equal to 1. On practical grounds, it is advisable to select for this a mean value; accordingly that hygrometric state was taken as normal, which made the above measurements give a value for the intensity of the glow lamp which was in exact accord with the previous extensive calibration of the same, namely, 8.8 liters

per cu. m. of dry air. The light unit designated by the Reichsanstalt in its official tests as the Hefner light is accordingly, taken exactly, the intensity of the Hefner lamp when the hygrometric state of the air is such that there are 8.8 liters of moisture per cu. m. of dry air."

The influence of pressure changes between the limits of 735mm. and 775mm. is shown to be a small one. If we call Δy the change in intensity corresponding to the barometric height b, we have:

$$\Delta y\ 0.0032 - 0.00011\ (b - 730) \text{ or}$$
$$\Delta y = 0.00011\ (b - 760).$$

This represents a variation of 0.1 per cent. per centimeter.

"To determine the influence of carbon dioxide, four series of observations have been carried out in the following way. Into the well-ventilated photometer room carbon dioxide was admitted, from a cylinder of the gas, and simultaneously with the photometric measurements, the proportion of carbon dioxide, was found by Hempel's method, the moisture also being determined. If we represent the intensity by y' and the proportion of carbon dioxide in liters per cu. meter of dry air by x', the following formula holds between 0.6 liter to 13.7 liters carbon dioxide — $y' = 1.022 - 0.0072\ x'$, in which the first constant on the right side of the equation refers to the intensity corresponding to the mean hygrometric state. Accordingly a variation in the amount of carbon dioxide by one liter, causes a variation of the intensity by 0.0072 Hefner light, that is by about 0.7 per cent."

"From a comparison of the formulae for moisture and carbon dioxide we see that equal volumes of watery vapor and carbon dioxide lower the intensity in unequal ratios, which are to each other as 1 : 1.30. Therefore volume for volume, the carbon dioxide influences the intensity to a greater degree than the watery vapor. Yet in reality the influence of the carbon dioxide is slight compared with the influence of the moisture on account of its smaller quantity. In the freshly ventilated photometer room of the Reichsanstalt the proportion of carbon dioxide in the air varied between 0.62 and 0.93 liters; to this variation corresponds a change in intensity of 0.2 per cent. which is quite within the limits of the errors of observation."

"We see therefore, that in a sufficiently large, well-ventilated photometer room, the carbon dioxide does not exercise a damaging effect. Very small rooms, especially all inclosed photometric apparatus may give rise to considerable errors, since the air in

them is very soon vitiated to a marked degree by the addition of watery vapor and carbon dioxide, and by the removal of oxygen."

By other than German photometrists the Hefner light has been shown rather scant favor, the chief objection to it being that the flame is too red in color. Dibdin indeed, made a rather extensive test of it, and found excellent results as far as steadiness goes, 90 per cent. of the tests being within one per cent. of the mean, and this in spite of the fact that he took the perhaps unwarrantable liberty of increasing the flame height to 51 mm., to make the intensity of the lamp equal to that of the British candle. The committee of the British Association found only four among 118 tests, which deviated more than two per cent. from the mean, and 11 which deviated more than one per cent. from the mean.

The Dutch Commission, to which allusion has already been made, dismisses the Hefner light from consideration because of

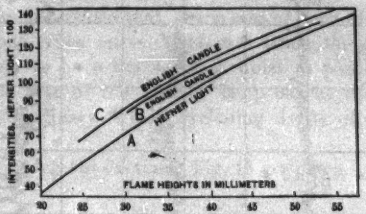

FIG. 14.

the instability of the flame. They found the following values for deviation in intensity. For a lamp using the optical flame measure, the mean deviation was $\pm$ 0.71 per cent. and the maximum deviation $\pm$ 2.83 per cent. : for a lamp using a sight the corresponding values were $\pm$ 1.08 per cent. and $\pm$ 4.32 per cent.

The bolometric investigation made by your committee upon the Hefner lamp is entirely corroborative of the previous testimony concerning the accuracy and steadiness of that standard. Typical results are given in Fig. 15.

Curve VII. of this figure was taken when a window in the farthest corner of the room was raised about 2 cm. Curve VII. (*a*) was begun 25 minutes after the end of VII., the lamp having burned during the interval, and the flame having been readjusted in height. The window was closed. The marked difference between the two curves is due to the stoppage of this slight draft.

VII
IX
XI
VII(a)
VII(b)
VIII
VIII(a)
X
XI
XI(a)
XI(b)
XI(c)
XII
XII(a)
XII(b)
XIII
XIII
XIV

FIG. 15

In taking curve X., the sensitiveness was adjusted at 32.5, or about double the standard sensitiveness for the other tests of the candles and of the Hefner lamp. Then a computation was made, from the law of inverse squares, of the distance at which it would be necessary to place the lamp in order to produce the ordinary deflection. The fact that the ordinates of this curve agree with those of the curves taken with a sensitiveness of 16.2 shows that the method of getting the sensitiveness by taking only first throws of the galvanometer needle, was an allowable one.

The length of time that the lamp had been burning, when curves VIII., XI., XII., and XIV. were begun, was 20 minutes or less. Each of these curves shows a gradual increase in the amount of radiation. This emphasizes the advisability of lighting the Hefner lamp a considerable time before it is to be used in photometric work.

It is to be understood that, in the case of each of these runs, except the one when curve VIII. was taken, the greatest care was exercised to have the room as quiet as possible. Curve VII. was the first of the Hefner lamp curves taken, and the need of extraordinary care in excluding drafts of air was not appreciated.

Data concerning the curves in Fig. 15 are given in the following Table X.

TABLE X.

	Time: Minutes on curve.	Mean ordinates and their mean.	Deviations from the mean ordinate of the curve.	Deviations reduced to percentages.	Deviations from mean ordinate of all the Hefner lamp curves.	Deviations from general mean reduced to percentages.
Curve VII.	0–5	38.81	−0.50	−1.27	+0.17	+0.44
	5–10	40.02	+0.71	+1.81	+1.38	+3.57
	10–15	39.64	+0.33	+0.84	+1.00	+2.59
	15–20	39.19	−0.12	−0.31	+0.55	+1.42
	20–25	39.03	−0.28	−0.71	+0.39	+1.01
	25–30	39.19	−0.12	−0.31	+0.55	+1.42
		39.31				
Curve VII. (a).	30–35	39.96	+0.44	+1.11	+1.32	+3.49
	35–40	40.27	+0.75	+1.90	+1.63	+4.22
	40–45	39.83	+0.31	+0.79	+1.19	+3.08
	45–50	39.54	+0.02	+0.05	+0.90	+2.33
	50–55	39.09	−0.43	−1.09	+0.45	+1.16
	55–60	39.03	−0.49	−1.24	+0.39	+1.01
	60–65	39.19	−0.33	−0.84	+0.55	+1.42
	65–70	39.27	−0.25	−0.63	+0.63	+1.63
		39.52				

	Time: Minutes on curve.	Mean ordinates and their mean.	Deviations from the mean ordinate of the curve.	Deviations reduced to percentages.	Deviations from mean ordinate of all the Hefner lamp curves.	Deviations from general mean reduced to percentages.
Curve VIII.	70–75	38.91	−1.12	−2.80	+0.27	+0.70
	75–80	39.83	−0.20	−0.50	+1.19	+3.08
	80–85	40.54	+0.51	+1.28	+1.90	+4.92
	85–90	40.86	+0.83	+2.08	+2.22	+5.74
		40.03				
Curve IX.	0–5	38.96	−0.54	−1.39	−0.38	−0.98
	5–10	38.62	−0.18	−0.46	−0.02	−0.05
	10–15	38.97	+0.17	+0.44	+0.33	+0.85
	15–20	38.87	+0.07	+0.18	+0.23	+0.59
	20–25	39.04	+0.24	+0.62	+0.40	+1.03
	25–30	39.03	+0.23	+0.59	+0.39	+1.01
		38.80				
Curve X.	30–35	38.89	0	0	+0.25	+0.65
	35–40	39.16	+0.27	+0.70	+0.52	+1.34
	40–45	38.62	−0.27	−0.70	−0.02	−0.05
		38.89				
Curve XI.	45–50	39.42	+0.83	+2.06	+0.78	+2.02
	50–55	40.50	+0.10	+0.25	+1.51	+3.91
	55–60	40.50	+0.25	+0.62	+1.86	+4.81
	60–65	40.92	+0.67	+1.67	+2.28	+5.90
		40.25				
Curve XI. (a) (b) and (c.)	70	39.37	−0.24	−0.61	+0.73	+1.89
	75–80	40.00	+0.39	+0.98	+1.36	+3.52
	85–90	39.46	−0.15	−0.38	+0.82	+2.12
		39.61				
Curve XII.	0–5	36.47	−0.90	−2.27	−2.17	−5.62
	5–10	37.21	−0.16	−0.43	−1.43	−3.70
	10–15	37.85	+0.48	+1.28	−0.79	−2.05
	15–20	37.94	+0.57	+1.52	−0.70	−1.81
		37.37				
Curve XII. (a)	25–30	35.53	+0.67	+1.85	−3.11	−8.03
	30–35	35.73	+0.47	+1.30	−2.91	−7.52
	35–40	36.38	−0.18	−0.50	−2.26	−5.84
	40–45	37.18	−0.98	+2.71	−1.46	−3.78
		36.20				
Curve XIII.	50–55	38.84	+0.15	+0.39	+0.20	+0.52
	55–60	38.74	+0.05	+0.13	+0.10	+0.26
	60–65	38.20	−0.49	−1.27	−0.44	−1.14
	65–70	39.00	+0.31	+0.80	+0.36	+0.93
		38.69				
Curve XIV.	75–80	38.46	−0.16	−0.41	−0.18	−0.47
	80–85	38.78	+0.16	+0.41	+0.14	+0.36
		38.62				

Mean ordinate of first five minutes of Hefner lamp curves = 38.645.
Reduced to true deflections = 38.66.

The highest point on the Hefner curves is 1.093 of the mean, and the lowest is 0.867, giving a total deviation of 22.6 per cent. This large deviation is not so significant, however, as a similar one in the case of candles, since in dealing with the Hefner lamp we have to do with an adjustable flame, and these fluctuations may indicate only that a slight readjustment was needed.

The most important question in regard to the Hefner lamp is the accuracy with which it can be adjusted to its normal light intensity. Some idea may be formed of this by noting in Table II. the percentage deviations of the first five minutes of each of the curves from the mean ordinate of the first five minutes of all the curves. The maximum deviation will be seen to be 8 per cent, while the mean deviation is 2.3 per cent.

Curves XI., XI. (*a*), XI. (*b*), XI. (*c*) show the results of successive attempts to adjust the height of flame to just 40 mm., the wick having been lowered between each one. No zero and sensitiveness readings were taken between the beginning of XI. and the end of XI. (*c*).

They are of special value to show the accuracy with which the flame can be adjusted under given unchanging conditions.

From the numerical data upon which these curves are based, the following table of mean ordinates has been compiled.

TABLE X (*a*).

Curve.	Mean ordinate.	Deviation from mean.	Percentage deviation.
XI. (5^{m})	39.42	− 0.14	− 0.35
XI. (*a*)	39.37	− 0.19	− 0.48
XI. (*b*)	40.00	+ 0.44	+ 1.11
XI. (*c*	39.46	− 0.10	− 0.25
Mean	39.56	Mean	0.57

If, now, the assumption be made that the light-giving efficiencies of the English and German candles and of the Hefner lamp are equal, it is possible to get their relative intensities by a comparison of the mean ordinates of their curves. Reducing the deflections as read on the telescope scale to angular measure and taking double the tangents of these angles, we have for the true deflections the following values:—

$$\text{English candle} = 41.06$$
$$\text{German candle} = 50.40$$
$$\text{Hefner light} = 38.66$$

From these values we get the following ratios:

$$\frac{\text{German candle}}{\text{English candle}} = 1.2275$$

$$\frac{\text{Hefner light}}{\text{English candle}} = 0.9415$$

Various determinations of $\frac{\text{Hefner light}}{\text{English candle}}$ are given in Table X (*b*).

TABLE X (b).

OBSERVER.	HEFNER. Eng. Candle.
[1] Sharp. Candles reduced for rate	0.872
[1] Sharp. Candles reduced for flame height	0.892
[2] Sharp & Turnbull. Integration of energy curves	0.941
Violle	0.98
[3] Reihsanstalt. Investigations, mean value	0.876
[4] Netherland Photometry Commission	0.921
[5] S. Schiele. Mean value	0.881

The value 0.94 rests on the assumption that the radiant efficiencies of the candle and Hefner flames are equal. Since the Hefner flame are distinctly redder in color than the candle flame, its radiant efficiency is probably smaller, and consequently the value 0.94 is too large. A difference in the radiant efficiencies of the two sources of less than 0.2% would serve to bring this value down to 0.88. The preponderance of evidence in favor of the value 0.88 is very great. It is probably true that the very

1. See Part IV of this report. The intensity of a Hefner lamp was determined by comparing it with the glow-lamp used throughout this investigation, the candle power of which was, subsequently, accurately known from many measurements.

2. Vide supra.

3. This is the mean of a long series of determinations made by different observers at different times using candles from various sources. The measurements were taken at normal flame height of 45 mm. See Beglaubigung der Hefner—1 lampe. Zeitschrift für Instrumenterkunde 13 p. 257.

4. An abstract in german by Krüss will be found in the Journal für Gasbeleuchtung und Wasserversorgung. 1894.

5. Scheile. Report of committee on the comparison of the Hefner lamp and German and English candles. Journal fur Gasbeleuchtung und Wasserversorgung band 32. 1889. p. 757. Also Dingler's Polytechnisches Journal, 274. p. 540. The measurements were made at normal flame height of 45 mm.

best way we have at the present time of determining candle power is to use the Hefner lamp and then to reduce by the use of this ratio.

X.

Platinum Standards.

(1) *The Violle Standard.*[1]—Violle conducted a long series of experiments upon this radiation of silver and platinum raised to various temperatures, and investigated also the light emitted by these metals when, after being melted, they have just reached the point of solidification. For platinum he obtained by the use of the thermo-pile, a curve of cooling.

This shows that molten platinum cools very rapidly at first, but as it nears its point of solidification, its rate of cooling becomes much slower and just upon solidification, there is a sudden rise in the intensity of radiation. After this, the cooling goes on rapidly once more. Violle's proposition for a light standard is this: He would define the unit of light as the light radiated by one square centimetre of platinum at its point of solidification. He melted the platinum by the use of the oxy-hydrogen blow pipe. A hollow cylinder through which cold water is circulating and which is pierced by an aperture one square cm. in size, is then passed above the molten metal. The light is reflected along the photometer bar, and its changes of intensity are followed by means of the photometer. The setting which is made at the time of the final increase in radiation (éclair) is the one which is taken as representing the intensity of the standard. From Violle's measurements, a very good result was obtained for this standard. Unfortunately, however, he used the Carcel lamp as a comparison standard in much of his work, and the deviation of his various measurements of the intensity of the platinum standard may be due entirely to his comparison standard.

But few physicists have investigated this unit, the reason probably being that it is so expensive to install and difficult to operate. At the Reichsanstalt,[2] investigations have been made by Lummer and Kurlbaum, in which the platinum was melted by Violle's method, and also by the use of an electric current. Their definitive results have not been published, but it has seemed advisable to them to abandon the use of the Violle standard as impracticable.

1. Violle, *Annales de Chem. et de Phys.*, Ser. 6, vol. iii., p. 373.
2. Lummer and Kurlbaum, *Electrotech. Zeitschrift*, vol. xv, 1894, p. 474.

Many attempts have been made to substitute for the large mass of platinum which Violle used, a thin strip, and to take measurements upon the platinum at its melting point rather than at its point of solidification. None of these has led to very favorable results. The best one probably is that proposed by Siemens. This has been carefully investigated at the Reichsanstalt. Hundreds of meltings were made, the greatest precautions being always employed, but the deviations were found to be as large as 10 per cent. or more. The conclusion reached from this by Lummer and Kurlbaum is that thin platinum foil, when heated electrically, often tears apart long before the whole of the radiating surface has reached the melting point.

Mr. C. R. Cross[1] investigated the radiation from platinum wires of various diameters when brought to the melting point by the electric current, and came to the conclusion that the fusing point depended upon the previous history of the platinum, the gas occluded, etc.

Draper, Schwenler and others have proposed, as a light standard, the light emitted from the surface of a platinum foil of definite dimensions when a given amount of electrical energy is being expended in it. None of these suggestions have led to any practical result.

(2) *The Lummer and Kurlbaum Platinum Unit.*—From their previous investigation of the Violle and Siemens standards, Lummer and Kurlbaum[2] concluded that absolutely pure platinum should be used as a radiating surface. They found that even a rough surface of the same became white when incandescent, and that moreover the platinum tended to purify itself when repeatedly heated and cooled. On the other hand, it would seem that the fixed temperature could be neither the melting point nor the solidifying point of the platinum, so that a method of defining the temperature of an incandescent platinum surface was sought for. These observers appear to have reached the end sought, even though the light unit obtained has not entirely fulfilled their wishes in respect to simplicity. "It demands," they say, "a complicated arrangement of delicate apparatus, and great experimental skill." They define the unit of light as that emitted by one square centimetre of incandescent platinum when the

1. *La Lumière Electrique*, 22, p. 507.

2. Lummer and Kurlbaum: *Elektrotechnische Zeitschrift*, vol. xv. (1894), p. 474.

ratio of the portion of its radiation transmitted by a specially designed water cell to its total radiation is equal to $\frac{1}{16}$. The platinum foil is stretched beneath a suitable covering arranged to make uniform the currents of air, and is heated by an electric current from storage batteries. The current required is from 50 to 80 amperes. By the introduction of resistance, the current is adjusted to such an intensity that the radiant efficiency becomes such as desired. In front of the platinum foil is a tube pierced with an aperture one square centimetre in size, and cooled by water circulation. The water cell is made of a cylindrical glass ring, closed by two parallel quartz plates. The quartz plates are each one mm. thick, and the thickness of the layer of water is 2 cm. The bolometer used, is that constructed by Lummer and Kurlbaum for such work, and consists of very thin platinum foil, which has been cut away in the form of a grid.

The standard which carries the platinum foil, is made to rotate through 90°, so as to face either the bolometer or the photometer. Comparisons of the intensity of the light were made with a glow lamp by means of the Lummer–Brodhun photometer. In determining the constancy of the radiation of the glowing platinum the bolometer was used. Throws of the galvanometer were taken at intervals of one minute, the result showing an admirable degree of constancy. In determining the radiant efficiency, the throws of the galvanometer showing the total radiation, and radiation through the cell were taken with the bolometer at such distances from the platinum foil that the galvanometer throws would be equal in the two cases; that is, the distances were in the ratio of $1 : \sqrt{10}$. In this way any errors due to the peculiarities of the galvanometer used were eliminated. It was found that an error of one per cent. in determining the radiant efficiency corresponded to an error of three per cent. in the intensity of light. Investigation of the radiation from chemically pure, and from commercial platinum foil showed a difference between them. At a high temperature the impurities of the commercial foil evaporate, so that the surface does not remain perfectly smooth, while the surface of the chemically pure foil becomes mirror-like. Reproductions of the standard could be made with chemically pure foil within one per cent.; with the commercial foil on the other hand, deviations of from two to three per cent. occurred. The aperture in the diaphragm could be measured within 0.01 mm. which corresponds to 0.2 per cent. change in light intensity. The cosine

law of radiation was found to be followed with such accuracy that no error resulted when the foil was not exactly parallel to the diaphragm. An error of 0.1 mm. in the thickness of the quartz plates of the water cell produced an error in the light intensity of 0.1 per cent., while an error of 0.1 mm. in the thickness of the layer of water produced an error of one per cent.

The greatest difficulty arose from the selective absorption of the material with which the bolometer strips were blackened. It was found to be impossible to get consistent results for the radiant efficiency with various bolometers covered with lamp-black, on account of the lack of uniformity in the thickness of the lamp-black covering on the different bolometers. A good result was obtained, however, by coating the bolometer strips with an electrolytic deposit of platinum black. A solution of definite composition was made, the bolometer strips and platinum strips were immersed in it, and a certain definite current was passed through for a definite time.[1] This resulted in a coating which was absolutely uniform, and has enabled consistent results to be obtained for the radiant efficiency. The conclusion reached as the result of these experiments is, that by using such apparatus and by taking careful account of all possible sources of error, a light unit is obtained which can be reproduced within one per cent.

XI.

The Blondel Arc Standard.

An isolated portion of the crater of the positive carbon of the arc has been suggested both as a primary and secondary standard. The suggestion came from Swinburne and S. P. Thompson independently, in 1892, and in a paper[2] read at the Electrical Congress at Chicago, the latter urges its adoption as a substitute for the Violle platinum standard.

That the light emitted from the crater is constant in quality and brightness was pointed out as early as 1878, by Capt. Abney. Recent measurements by Violle indicate a constant intrinsic brightness quite independent of the power expended in the arc.

1. For a bolometer of 8 cm.^{2} area, the solution is as follows: Platinum chloride, 1 part; water, 30 parts; Lead acetate enough to make one part to 4,000 parts water. The temperature of the solution should be 20°; the E. M. F. 4 volts; the current 0.25 ampere. The current is allowed to pass for 2 minutes. The bolometer strip is placed between two platinum electrodes so that both sides are equally blackened. See *Zeitschrift für Instrumentenkunde*, Aug. 1895.

2. "Proc. of the International Elec. Congress," p. 267.

His experiments were conducted between the wide limits of 10 and 400 amperes and corresponding power values of 500 and 34,000 watts. Throughout this range Violle found the spectrophotometer to show no variation in quality of light emitted—a result which was corroborated by a photographic method. These results lead Violle to announce absolute constancy in the temperature of the crater surface—a constancy which he believes to be due to a true ebullition of the carbon at this point. This view is in accordance with those advanced by S. P. Thompson.

The temperature of the positive carbon Violle has determined to be 3,500°. This value, obtained by a calorimetrical method, must be considered as only approximate, owing to lack of knowledge of the specific heat of carbon at this extreme temperature.

To Blondel[1] is due the first attempt to put this standard into a working form. In the form of lamp adopted by him, an obliquity of 40° to 60° from the vertical is given to the crater surface by inclining the carbons about 20° from the vertical. The extent of the incandescent surface exposed is regulated by a diaphragm pierced by holes of different sizes, any one of which may be brought behind an opening in the screen by a simple rotation. The screen is cooled by a stream of water as in the Violle standard. For arc light photometry an opening of one square millimetre is recommended. The illumination on a screen 4 m. distant is then about 10 candle-metres. The best results are obtained by maintaining an arc of 5 mms. with a current density of 0.2 ampere per square mm. It is, of course, essential that the operator satisfy himself that he is getting light from the region of maximum brightness before making a photometer setting. This is insured by momentarily dropping a small lens in front of the hole and projecting an image of the carbon points upon a screen placed at right angles to the photometer bar. Blondel has determined the intrinsic brightness of this source to be 158 candles—the extreme figures in his measurements being 150 and 163.

With reference to this standard, a question of paramount importance is that of the influence of the quality of the carbons upon the intensity. Since the impurities are volatilized at a relatively low temperature, a surface of pure graphite is left as the light-emitting coating of the crater, and it might be supposed that moderate variations in the quality of the carbons would be

1. Blondel, "Proc. International Elec. Congress," p. 323.

without effect on the intensity of the light emitted. Blondel's researches in this direction indicate the contrary. For cored carbons he obtains values as low as 130 candles for the intrinsic brightness. Even with homogeneous carbons there is a considerable variation—so much, indeed, that the utility of the device for anything but a secondary standard for arc light photometry is exceedingly doubtful.

Bolometric curves of an improvised arc standard consisting of a Schückert focussing arc lamp with oblique carbons, in front of

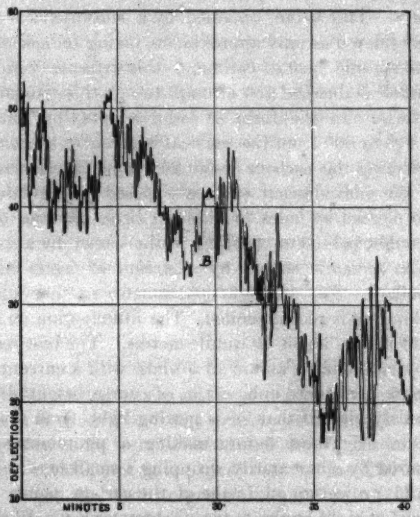

FIG. 16.—Between the points A and B there was a time interval of 20.5 minutes.

which a diaphragm was mounted, are shown in Fig. 16. It would not be fair, perhaps, to claim that in this experiment the conditions proposed by Blondel were successfully fulfilled. It may be said, however, that a reasonable attempt was made to do so on the part of practiced experimenters. The range of the sudden fluctuations which the curve exhibits may be taken as indicative of the difficulties which those are likely to encounter who use such a standard.

XII.

Kerosene Oil Lamps.

These lamps have been quite extensively used as secondary standards, and have been usually found very satisfactory.

Heim,[1] in studying the efficiency of various sources of light, used a kerosene lamp as a secondary standard, with good results.

A screened kerosene student's lamp has been found to give good results when used in the Edgerton photometer.[2] The screen was pierced with a round hole 12 mm. in diameter. With different kinds of kerosene, there was a slight difference in intensity. A series of ten observations, each with flame height varying from 65 mm. to 300 mm, showed a maximum variation in intensity of only 5 per cent. Changes in flame height amounting to from 12 to 25 mm. made inappreciable differences in intensity. The chimney used had a considerable influence on the intensity.

Herr von Hefner-Alteneck[3] has emphasized the points of excellence of kerosene lamps, claiming that they are superior to the Carcel lamp.

'In some of the measurements of the intensity of a candle as a function of the height of its flame, a kerosene lamp with an Argand burner, similar to the ordinary student lamp burner, was used. The upper part of the chimney was covered by a tightly-fitting cylinder of ferrotype iron, in such a way that the top of the flame was entirely hidden. This furnished a very steady source of light, after it had been burned long enough for the parts to become thoroughly warmed, and its intensity was unaffected by slight adjustments of the height of the flame, provided only that the flame was always high enough. Its intensity varied enough from day to day, however, to make its indications unreliable without a daily calibration.

A convenient form of kerosene lamp requiring no chimney, in many ways suited to photometric purposes, is the Hitchcock mechanical draught lamp, made at Watertown, N. Y.

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1. Heim, *Lumière Électrique*, 26, p. 220.
2. *Polytechnic Review*, 1878, 5, p. 161.
Dingler's Polytechnisches Journal, 229, p. 48.
3. Von Hefner-Alteneck. *Elektrotech. Zeitschrift*, 4, p. 445.
4. Sharp. *Phys. Rev.* Part IV of this Report.

XIII.

The Carcel and Keats Lamps.

The Carcel lamp has been in use for very many years in France, and in the hands of experienced operators it is capable of yielding good results. The combustible is colza oil, the normal rate being 42 grams per hour. The most exhaustive tests of its behavior are those of Audoin and Bérard,[1] made under the directions of Dumas and Regnault. In these experiments the effect of the height of the wick, its nature and the height of the contraction in the chimney were studies with reference to the consumption of oil. The results indicate that it is unjustifiable to take the intensity as proportional to the rate of burning unless these variables are very carefully looked after, that is to say, unless the lamp is always used under conditions which it is very difficult to maintain constant.

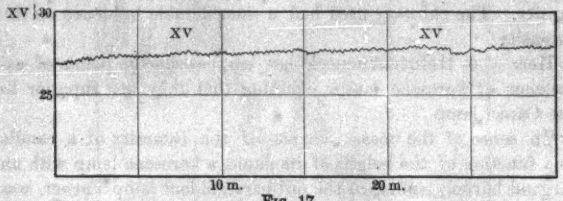

Fig. 17.

In countries other than France, the Carcel lamp has met with little favor, the results of tests showing considerable variations in behavior. Dibdin's results (1888) show a mean deviation from 33 sets of observations of 1.34 per cent., disregarding signs. The maximum was 4.1 per cent., 32 per cent. of the tests being within one per cent. of mean.

The Keats lamp shows a better behavior. Thus Dibdin found 71 per cent. of his observations within one per cent. of the mean, and a maximum variation of 3.4 per cent. On the strength of these comparative results he rejects the Carcel lamp in favor of the Keats. His report of 1888 shows, for the Keats lamp, a maximum deviation from mean of 9.4 per cent., 39 per cent. of the observations being within one per cent. of mean. He says: "The Keats lamp has been tried most thoroughly, but has failed in

1. *Annales de Chemie et la Physique*, 3d. series, vol. lxv.

practice to realize all that was formerly hoped for it, not so much from any inherent defect, as from the severe trial it makes, as compared with other systems, upon the patience of the observer."

Figure 17 contains a curve which is typical of the behavior of this source of light. It will be noted that the rapid fluctuations, characteristic of naked flames are almost absent.

The curves obtained in the study of the Carcel lamp all show clearly the great gain in steadiness of the flame resulting from the use of a proper chimney. The deviations were, for the most part, no larger than the swings of the galvanometer when the bolometer was unexposed to radiation. The variations extending over a considerable period of time are, however, by no means inconsequential. In the course of one test there was a total deviation in the mean ordinates of the five minute periods of 5.1 per cent., taking place in ten minutes. Another experiment shows a deviation of less than 0.8 per cent. in 35 minutes, and this is perhaps a more typical illustration of what may be expected from this lamp when burned under the best conditions. The highest and lowest points on any of the Carcel curves are 29.9 and 25.4 respectively, corresponding to deviations from the mean of the curves of + 5.7 per cent. and — 12.5 per cent., or a total of 18.2 per cent. The maximum deviations, for periods of five minutes, are + 5.3 per cent. and — 8.4, giving a total of 13.7 per cent.

XIV.

The Acetylene Flame.

A preliminary report has already been made to the Institute no the use of the acetylene flame as a light standard.[1]

In France, Violle has given some attention to this standard, and has published a note concerning it.[2] The latter recommends the use of a flat flame, maintained at a pressure of 30 cm. of water, the gas being mixed with air drawn in at the base of the burner. The entire flame may be used as the light source, or it may be screened to any desired amount. Under former conditions a consumption of gas of 58 litres per hour is reported as furnishing a light twenty times that of illuminating gas in an or-

1. Fessenden, Transactions, p. 507, June-July, 1895
2. *Comptes Rendus*, Jan. 13, 1896.

dinary burner. The distribution of luminous intensity in the spectrum of acetylene is found to coincide quite closely with that of platinum at the melting point.

XV.

Incandescent Oxides.

Concerning the sources of light which depend upon the incandescence of a glowing metallic oxide, a sufficient amount of

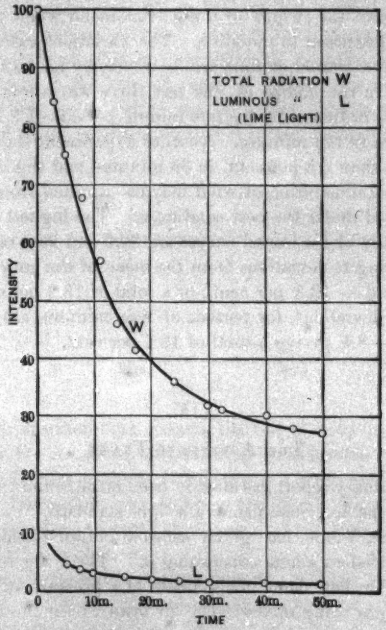

Fig. 18.

work has been done to show that, as a class, they possess a property fatal to their use as light standards. This property may be illustrated by means of measurements made by a member of the Committee on Light Standards.[1]

1. Nichols and Crehore, *Phy. Rev.*, vol. i, p. 161.

In these measurements, the radiation from the glowing oxide of calcium, namely, from a cylinder of the Drummond light brought to incandescence by the action of the oxy-hydrogen flame was tested by means of the thermo-pile and galvanometer. The intensity of radiation, as determined by means of the deflection, was measured as function of the time from the instant of ignition, for a period of fifty minutes. Similar curves were taken for the radiation capable of passing through water cells, which were interposed between the thermo-pile and the cylinder.

From the results, shown graphically in Fig. 18, there is seen to be a rapid and continual falling off in intensity, which, in the case of the total radiation, amounts to 60 per cent. during the first

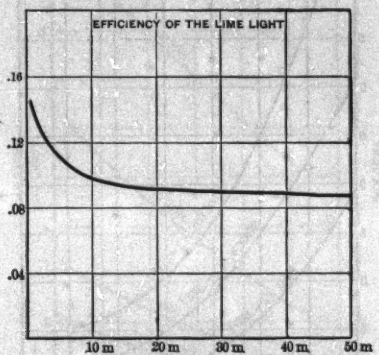

FIG. 19.

twenty minutes after ignition. This continues, but with decreasing rapidity, throughout the remainder of the time. At the end of fifty minutes, the intensity of radiation in terms of the initial intensity is about 27 per cent. By plotting the ratio of the curve of total radiation to that of luminous radiation, we obtain the radiant efficiency of the lime light as a function of the time. Were this curve a horizontal line, the conclusion would be that the quality of this source remained a constant, although the amount of light which it sends forth diminished. The curve which is given in Fig. 19 indicates, however, that the initial efficiency, which amounts to about 15 per cent., falls off in the course of fifty minutes to less than 9 per cent. The former cor-

responds to the radiant efficiency of the magnesium light, a value which is in accordance with the character of the light emitted by the freshly ignited lime. The latter shows a degree of incandescence inferior to that of the ordinary arc light. This change is in complete corroboration of the results of earlier photometric tests of this source.[1]

The measurements were supplemented by a photometric study of the lime light in the course of which the decadence of three

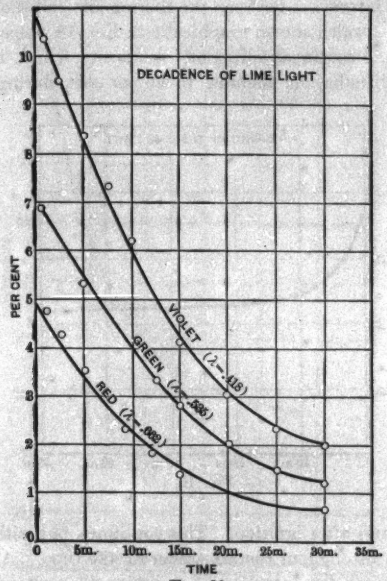

FIG. 20.

typical wave lengths was computed as a function of the time. These were, violet wave length 418, green wave length 535, and red wave length 662. Measurements of these regions of the spectrum during 30 minutes from the time of ignition, gave a curve the character of which is indicated in Fig. 20. It will be seen that in all three cases there is a very rapid diminution of

1. See Pickering, "American Academy of Arts and Sciences," vol. xv; also Nichols and Franklin, *American Journal of Science*, vol. 38, p. 103.

light. The falling off of the value amounts to more than 80 per cent. during 30 minutes. From these values, and from a complete study of the spectrum of lime under the conditions which it reaches after 30 minutes, it is possible to plot curves showing the relative distribution of light in lime light and gas light at different times after ignition. In Fig. 21 a set of such curves are given, which show graphically the manner in which the lime light falls off in intensity and varies in quality during the first half hour of its incandescence. These curves are very similar to those which

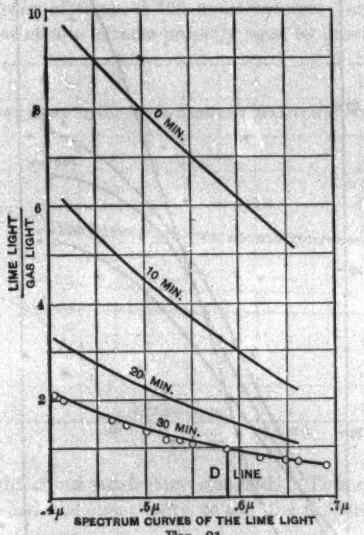

FIG. 21.

have been obtained with oxide of zinc heated electrically to a temperature of 1,000°[1].

Cursory observations, made in cases where disks of magnesium, oxide and zircon had been substituted for the lime, showed analogous behavior, although there seemed to be reason to believe that the decadence was not so rapid as in the case of lime.

1. Franklin, *Amer. Journal of Science*, vol. xxxviii., pp. 108.
See Nichols and Snow, *Philosophical Magazine*, (5) vol. xxxii., pp. 401.

Measurements made with the Welsbach incandescent mantle burners afford abundant evidence of the same tendency on the part of this source of light. Records of candle power and gas supply have been made covering several hundred hours[1].

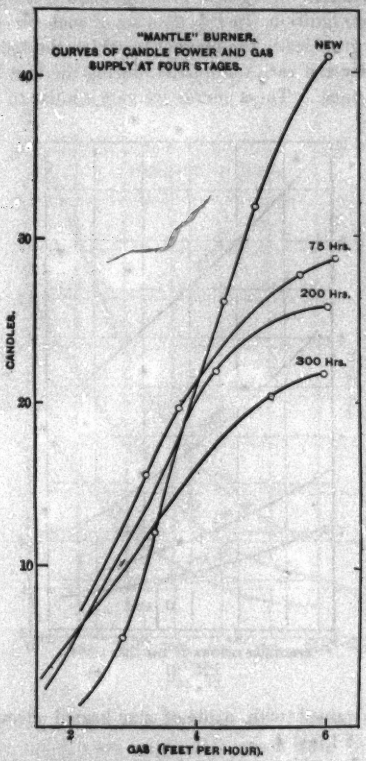

FIG. 22.

Fig. 22 which is constructed from the measurements of Ida M. Hill[2] shows the relationship between the candle power and gas,

1. See thesis of E. V. Stebbins, Mss. in the Library of Cornell University, also Nichols *Laboratory Manual of Physics and Applied Electricity*, vol. ii., p. 339.
2. Ida M. Hill, thesis in the Library of Cornell University, 1890.

supplied to a mantle burner of the form in use in 1890, when new, at the end of 75, 200 and 300 hours. Fig. 23 shows the curve of decadence with age of a later type of mantle burner, from the measurements of Mr. Stebbins. It is interesting to note the resemblance between the latter curves and the like curves of the incandescent lamp. It has recently been pointed out as a result of microscopical examinations of this burner, that there is permanent cause of the falling off in the candle power, namely a diminution in the radiating surface[1].

It should be said in this connection, that the rate of decadence of such burners after about 100 hours becomes very slow. It is possible that mantle burners properly aged by previous incandes-

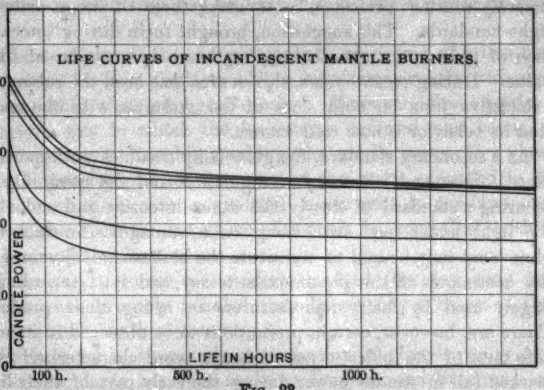

FIG 23.

cence might afford satisfactory standards. This committee has not as yet had the opportunity to test the properties of such a standard.

These data make it evident that if the light from an incandes-

1. St. John found that the net work of the mantle when new showed interstices nearly filled with the oxide, whereas in 100 hours the material had largely disappeared reducing the net work to a skeleton. St. John estimated the diminution in radiating surface at about 50 per cent. which would very nearly account for the falling off in candle power. (See Wiedemann's Annalen, vol. 56, p. 433.) Photometric measurements of this source show, however, a greater relative loss of violet than of red light, and measurements of the radiant efficiency show that this likewise falls off. These two facts always accompany one another, and they indicate a change in the radiating power of the material.

cent metallic oxide is to be used in the production of a primary light standard, the method of composition must be one which continually introduces a freshly formed film. The light of a burning magnesium ribbon fulfills this condition, but there is as yet no practicable method of controlling the combustion of such a ribbon.

XVI.

The Glow Lamp as a Standard of Light.

It was at one time thought by some, that under carefully prescribed conditions of manufacture, glow lamps would give a sufficiently constant performance to make them of use as primary light standards. This suggestion, brought forth during the early days of glow lamp manufacture, has been shown to be of little value. During recent years, this source has been the subject of exhaustive tests on both sides of the Atlantic, with the result that its behavior is now well known.[1]

As a secondary standard, the glow lamp occupies an important place. Ease and constancy of regulation, and the possibility of securing a standard of nearly the same intensity and color as the light under test, are among its advantages. In fact, the glow lamp may be said to constitute the best secondary source at the command of the photometrist to-day, and it is accordingly largely used by lamp manufacturers in rating their product. There are, however, certain precautions to be observed in its use. Life tests of the older types of lamps were characterized by a marked fall in candle power during the early part of their life, after which the change became much more gradual. Recent tests by Ayrton and Medley[2] show, in the Edison-Swan lamps, an initial rise in the candle power. This rise, amounting in some cases to thirty-three per cent. during the first 124 hours of life, is not accompanied by a proportionate increase in energy consumed; that is, the efficiency rises during the early life of the lamp. The spark test shows in these lamps an improved vacuum after they have been burning for some time. That the

1. See, among others: Peirce, Transactions, vol. vi, p. 293; Nichols, N. Y. Electric Club Pamphlets, No. 27 (1890), and Thomas, Martin and Hassler. Transactions vol. ix, p. 271.

2. Tests of Glow Lamps, *Phil. Mag.*, May, 1895.

change in vacuum is the cause of the increasing light intensity does not seem to be established by experiment, since the improvement in the vacuum is found, to a marked degree, in lamps which show but slight rise in candle power.

But whether the early life of a lamp be marked by rise or fall in candle power, it is in almost all cases the period of most rapid variation, and hence it is important that this stage should be passed in lamps used as light standards. It is also important that the lamp should not be strained by an excessive voltage, as its later life will be accompanied by rapid decline in candle power. As soon as an incandescent lamp has been standardized, one or more copies of it should be made and put aside, in order that the original lamp may be examined at any time for change in intensity.

The steadiness of the energy supply is, of course, of prime importance. It is difficult to obtain satisfactory results with any source other than storage batteries. Moreover, the electrical measurements to which the intensity is referred must be made with accuracy. Roughly speaking, the candle power of a glow lamp is proportional to the cube of the watts expended in it, and to secure a constancy within 1 per cent. in the luminous source, the electrical energy supplies must be controlled within $0.4\frac{1}{3}$ per cent. at least.

How very accurate a secondary standard the glow lamp becomes when properly handled, may be seen by a report of the Reichsanstalt in Charlottenburg.[1]

Perhaps the most accurate investigation of glow lamps as secondary standards, has been made by Lummer and Brodhun[2], at the Reichsanstalt. They compared with each other two 65-volt lamps run at a pressure of a little less than 55 volts, determining by means of one, the change in intensity of the other when the latter was operated many hours.

In order that photometric measurements might be significant to within 0.1 per cent., measurements of current and potential were made accurate to within 0.01 per cent. using Clark cells and resistances of zero temperatures coefficient. Results of the comparison of two lamps, L and R, are given in Table XI.

1. *Zeitschrift fur Instrumentenkundes*, vol. , p. .
2. Lummer and Brodhun, *Ze tschrift für Instrumentenkunde*, 10, 119, 1890.

The position of the glow lamp as the most reliable of secondary standards may be regarded as established. He who seeks to use it as a primary standard, will, however, have to face a number

TABLE XI.

Hours burned. R	4	Ratios of Intensities. L/R
1	1	0.8779
20	2	0.8764
62	3	0.8742
154	8.5	0.8724
211	13.5	0.8677

of difficulties. One of the chief of these consists in the fact pointed out some years since by Evans[1], that treated and untreated carbons possess very different properties. Weber[2] in his paper on the general theory of the glow lamp has determined the

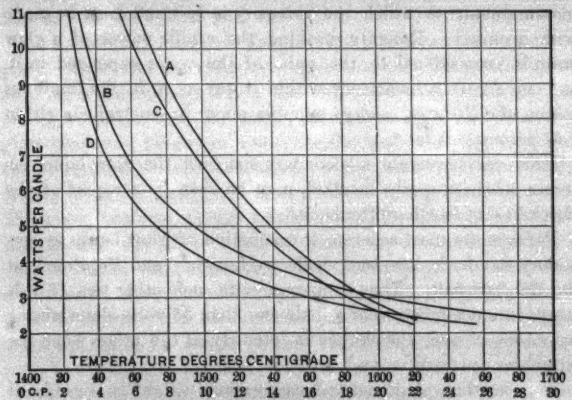

FIG. 24.—Weber's General Theory of the Glow Lamp.

Lamp of the Allgemeinen Elektricitäts Gesellschaft.
A, Watts per Candle and Temperature.
B, " " " C. P.
Sunbeam Lamp.
C, Watts per Candle and Temperature.
D, " " " C. P.

emissivity of the two, and has shown that they are to be regarded as distinct varieties. That the difference between the

1. Evans, "Proceedings of the Royal Society," 1886.
2. Weber, *Physical Review*, vol. ii., p. 112.

black and the gray surfaced carbon is not negligible will be evident upon inspection of the curves in Fig. 24. These curves, which have been derived from data given by Weber, give the relations between efficiency and temperature, and efficiency and candle power respectively in the case of lamps with treated and with untreated filaments.

One of the members of your committee[1] has shown further

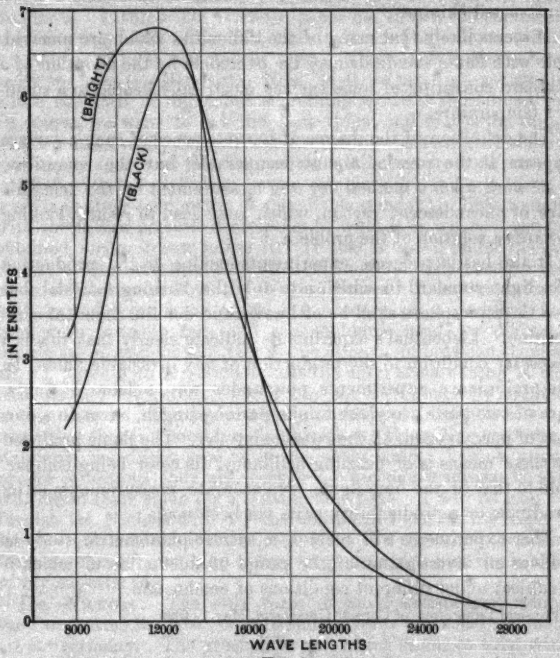

FIG. 25.

that the energy curves of the spectra of lamps with bright and with black filaments are far from being identical.

In Fig. 25 two such energy curves are presented. It will be seen that the curve of the lamp with bright filament has its maximum at a shorter wave length, and that the distribution of energy differs greatly in the two cases.

1. Nichols, *Physical Review*, vol. ii., p 260

Conclusion.

It is evident from the foregoing summary of previous photometric researches and from the report of the work of this committee, that of all standards thus far used, candles are the least reliable. It is also evident from the bolometric curves that naked flames are subject to sudden and rapidly recurring fluctuations that may be almost entirely eliminated by the use of a properly constructed chimney.

It seems likely that many of the difficulties which are unavoidable with flame standards may be overcome by the adoption of a standard consisting of some surface electrically heated to a standard temperature.

The definition of the degree of incandescence of such a surface appears at the present almost insuperable, but the committee is at work upon a method for the measurement of the temperature of incandescent carbon, which may lead to results looking towards a solution of the problem.

It also has in progress experiments looking to the production of a light standard in which not only the burning material but also the atmosphere shall be of known and definite chemical composition. Liebenthal's experiments indicate clearly that this is a necessary condition to the production of any invariable flame. In the preliminary experiments now under way, a flame of a mixture of two parts acetylene to one part hydrogen, burns in a current of pure oxygen, all the gases being dry. The flame produced by these means is of dazzling brilliancy, its color being comparable to that of the lime light. No accurate measurements of its steadiness or reproducibility have yet been made.

This experiment will include a spectro-photometric study as well as an investigation of the range of fluctuation to which it is subject under different conditions of combustion.

Physical Laboratory of Cornell University, May 1, 1896.

Discussion.

The President:—Gentlemen, this is an exceedingly interesting subject, and a very difficult one to deal with. In the last week or so the Institute has had requests from several outside sources to attempt to fix a standard of light. It is a matter which the Committee has taken up in the most exhaustive way, and any light that the members may be able to throw upon the subject in the way of discussion will be very welcome.

MR. J. W. HOWELL:—I have some knowledge of the pressure which is being brought to bear upon the INSTITUTE urging them to establish a standard of light. I think it is indeed one of the most important subjects that has been brought before the INSTITUTE in a long time. I fully appreciate the absolute lack of a commercial standard of light, and I know that because scientific men have been unable to refer light to an absolute standard, they have been very loth to establish any arbitrary standard. That has left us in a condition of chaos, you might say, in regard to light standards. I think Dr. Nichols' paper has shown the condition of affairs very well. The fact that there are half-a-dozen different sources of light accepted by people as standards indicates how badly we need *one* standard. Now, what we need is—not an absolute standard of light, but something which is reproduceable. Of course, we want to get the best thing, and that is the thing which is most easily reproduceable. I think the INSTITUTE should continue the work of this Committee until they are well enough satisfied with their labors to issue a commercial standard; to state what is in their opinion the best available standard of light to-day, with the fullest possible description of what it is, where it can be obtained, and just how to use it. If that is issued under the authority of the INSTITUTE, I think it will undoubtedly become the commercial standard of the United States. In my experience with incandescent lamp work, the absence of a standard has been very severely felt, and the standards used by different people are so various that there is no agreement between them at all. I agree with Dr. Nichols that the amyl acetate lamp is the best that is known to-day, but it has not been generally adopted in this country. The amount of light obtained from it is so very small that that is a considerable objection. Regarding secondary standards, we always used an incandescent lamp. I think, under proper conditions they are very good secondary standards, and will retain their value for a considerable time. I will be glad to furnish Dr. Nichols with all the assistance I can in this respect, for we have used the incandescent lamp as a secondary standard for a number of years, and I shall be glad to give him the benefit of my experience.

DR. NICHOLS:—The only form of amyl acetate lamp which the Committee has tried, is the standard form furnished the makers in Germany. The great difficulty which seems to exist with that lamp is the redness of the flame. The flame is, I might say, of a ruddy color, and there is a very considerable color difference between it and gas even, and still more between it and a high efficiency incandescent lamp. It has been shown by the very painstaking investigations of certain German students of this subject, that the atmospheric conditions, unless artificially controlled, are sufficient to produce a definite fluctuation in those standards, which consist of a naked flame. For example, the amyl acetate lamp has been tested at frequent intervals for two

or three years, and it has been shown to vary with the time of year, giving more light in certain months than in others. These curves of fluctuation vary with the meteorological conditions, especially with the amount of moisture in the atmosphere. The variations are such that it seems as though we must abandon the open air as a source of supply for flames and introduce instead of it an artificial supply. That is the idea which the Committee had in mind in the lamp which I have outlined on the blackboard, in which the hydro-carbon should be entirely enveloped in an artificial atmosphere of constant proportions, and thus be as far as possible free from the influence of meteorological changes.

Mr. Carl Hering:—I would like to ask Dr. Nichols whether he has tried an amyl acetate lamp with a flat flame in combination with a Methven screen. It seems to me that such a combination might meet some of the objections to the use of that lamp.

Mr. C. P. Steinmetz:—I have been very much interested in the work done by the Committee with the acetylene flame as standard, since from my experience with acetylene I believe, that, if developed, the acetylene lamp would give an ideal standard of light, due to the ease of producing acetylene chemically pure, and the white color of the light, which is similar to that of the incandescent and the arc light, and thereby more convenient than the reddish amyl acetate flame. I have experimented a little with acetylene as an illuminant, and derived the best results with small flames, by having the gas issue at a low pressure, of 1 or 2 centimetres water column, through the hole of an ordinary blow-pipe. This gave a flame of something like 4 to 5 centimetres hight, of intense whiteness, of probably something like 25 candle-power intensity.

There is one source of contamination, however, to be feared in the acetylene when derived directly from calcium carbide, which while immaterial for the use of acetylene as ordinary illuminant, would be objectionable for a standard of light. The acetylene is liable to contain a small percentage of hydrogen, which even in small quantities noticeably reduces the intensity of light. Therefore for the use in a standard lamp, I think it desirable to produce the acetylene gas from liquid acetylene, which is necessarily free from hydrogen.

[The paper by Mr. D. McFarlan Moore, presented April 22d, was then taken up for discussion, as reported in the March issue of the Transactions.]

[COMMUNICATION BY PROF. R. A. FESSENDEN RECEIVED AFTER ADJOURNMENT.]

I do not think any one can read this paper without feeling an admiration for the manner in which the writers have done the work they set out to do, and an indebtedness for the knowledge they have given us.

It is apparent that a standard must have the following properties, amongst others, if it is to be satisfactory.

It must not use a wick.

It must not be much affected by draughts.

It must not be much affected by moisture or by change of barometer.

It must burn a definite chemical compound.

In January, 1895, I notified the Chairman of the Committee, Prof. Houston, that I was working upon an acetylene standard, and in April I made a report of progress which was printed in the June TRANSACTIONS.[1] I regret to say that on account of pecuniary difficulties the University has been unable to contribute the amount promised, and work has hence been carried on but slowly. At that time, as is mentioned in the report, it was found that the most suitable pressure was 12 inches, and that the flat flame gave the best results. It is a source of gratification to know that M. Violle, as a result of his experiments, (*L'Elect.* p. 76, 1896,) has also found a pressure of 30 cms. and a flat flame to be most suitable, so that this point may be considered as decided.

My further work on the subject has been devoted to ascertaining the best means of producing the flat flame, since the object aimed at is the production of a standard which can be duplicated in any instrument shop by any physicist in the same manner as a Clark cell. The most obvious plan is that of using a narrow slot and adjusting the edges at a certain distance apart, the distance being measured by interference methods. On working out the plan in detail, however, it was found that the expansion of the materials used would be apt to introduce errors which could not be neglected. Moreover the method would be difficult and expensive. After some amount of experimenting, the method shown in the drawing;[2] in which two jets of gas from two circular orifices of the same diameter impinge upon each other at an angle of 90°, thus forming, as experiment shows a very evenly luminous flame, was finally decided upon, for the following reasons.

It is easily shown, by very simple reasoning, that if we have to make an orifice of a certain definite area, that of all shapes, the circular one is that in which a given amount of error will make the least amount of percentage error. Thus, with a slot one inch

1. TRANSACTIONS, vol. xii., p. 500.
2. In the Figure, A and C form one toroidal chamber, surrounding B

long and $\frac{1}{100}$ inch width, an error of $\frac{1}{1000}$ inch would make ten per cent. error in the area, while if the orifice were circular and of equal cross-section, the same absolute error would make less than two per cent. of difference.

Moreover the circle is of all forms that most easily made accurately. With a long reamer having but slight taper. the diameter can be produced with great accuracy by noting how far the reamer has been introduced into the hole and calculating from the taper.[1] Moreover in case of wear, the tubes can easily be swaged down slightly, and re-reamed. The adjustment is easily made by inserting needles into the tubes and moving till the points touch. The reservoir below the jet may be kept at constant temperature as in the writer's benzol standard, and the air supply may be regulated, as suggested by the writer.

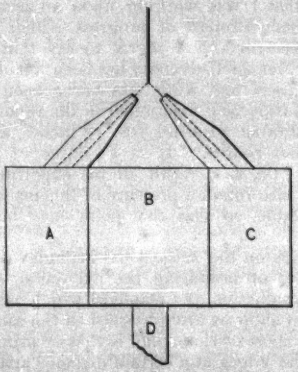

FIG. 1.—Space B filled with wire gauze to prevent wave disturbances. Pressure readings taken at A and C. D, pipe leading to acetylene producer.

(Report to Prof. Houston, Chairman of Committee, Dec. 9, 1893, with respect to the Methven standard.)

Though the work done has been small, two important phenomena have been noted with respect to the acetylene standard.

First: It is but slightly affected by draughts, the effect being small as compared with that on other standards. This is no doubt due to the high pressure at which the gas is burned, *i. e.*, 30.8 cms.

Second: The effect of moist air is much less than that with other standards. This I attribute to the very high temperature of the acetylene flame. Since also the amount of air required to

1. A drift has since been found to be better than a reamer. The drift pin is measured by Dewer and Fleming's optical method.

produce a given candle power is only about seven per cent. of that required with ordinary gas, we see that there is ample reason why the acetylene should be, as my observations show it is, much more independent of atmospheric conditions than other standards.

I regret that at present, lack of facilities has prevented my making quantitative measurements of this gain, but it will be seen from the above considerations that there is good reason to believe it is very great.

In the reports forwarded by the writer to the Chairman of the INSTITUTE Committee during the years 1893-5 some considerations were presented which were omitted in the condensed report, owing to lack of space. As these reports have not been published and as this has led, in at least one case to an unnecessary repetition of work done by the writer, I will give the substance here. With the exception of those paragraphs enclosed in brackets I have copied the reports as closely as possible.

First: It is not necessary or even desirable that we should have a standard of light accurate to within more than ½ per cent. If we had it we could not use it. In comparing an incandescent lamp with the standard, the spectrum distribution would be different, (unless of course we chose an incandescent lamp as standard, when the same remarks would apply to other sources.) Now, Langley's researches (Trans. *Am. Jour. Science*, Nov. 1888,) show that no two eyes are affected in the same ratio over all parts of the spectrum, and that apparently young people are more sensitive to blue and less to red than older. Consequently if we have two sources, A and B, one A, a rather blue light and B rather red, then one man may record A as much the brighter and another observer may on testing find for his vision the exact opposite to be the case. If these differences were small they would still be important, but when it is pointed out that variations of 50 per cent. are very common and that in some cases estimates differ by 1000 per cent. it will be seen that any great accuracy in the standard is simply useless. Of three observers tested by Langley, one was most sensitive to rays of wave length $\mu = .57$, one to those of $\mu = .52$ and one to those of $\mu = .53$ and from the shape of the curves given it is seen that if these observers had to compare an arc and an incandescent lamp they would have arrived at quite discordant results.

It would seem therefore that what we need is:

(*a.*) *A Standard of Radiation.*—The standard proposed in my report (Oct. 30, 1893,)is a copper ball, thick, blackened, and having a platinum wire wound inside it of such resistance that when one ampere of current is passing through the resistance 4π watts should be radiated from the ball. Or, as an alternative suggestion, that the resistance should be one ohm. I consider the latter the better.

(*b.*) *A Primary Standard of Light.*—This to be the light effect of one watt of D line light. This to be taken as standard and the

spectrum divided into, say, five parts and each compared with the sodium light. (D. line.) The mean of the result of tests on several thousand different individuals, of all ages, to be taken as a provisional optical factor.

Any light source would then be defined as follows, for example, 12/1.2.4.3.2., as regards radiant energy in the visible spectrum, meaning thereby that the total energy in the visible spectrum was 12 watts, of which one watt was in the first section of the spectrum, two in the second, etc. By multiplying the each radiation term by its corresponding optical factor, derived as above, we would get the optical effect, as it would be for the average eye. Represented thus, 3290/90—300—1600—800—500, meaning that the average eye would see the source as possessing a total intensity of 3290, divided into 90 units in the first section, etc.

It is evident then, that the accuracy which we shall need in any general standard of light will depend upon the limits of the probable error in determining the optical coefficients of the various wave lengths. In view of the facts that two eyes may differ in their estimate of the intensity of a colored source compared with sodium light by as much as fifty per cent. I believe that under no circumstances will this probable error be less than $\frac{1}{4}$ per cent., and that this therefore fixes the limit of desirable accuracy. It is of course impossible to say this definitely, as we have not at present sufficient experimental data, but I believe I am on the safe side in my estimate.

(*c.*) Having then a unit of radiation, easily and accurately reproduceable to $\frac{1}{10}$ of 1 per cent., and a unit of optical effect capable of being defined equally accurately, and a set of approximate optical effect coefficients we need now a *set of secondary standards* for practical work. I have suggested the Methven flame and incandescent lamps as such standards. (This was before work on the acetylene standard was begun. This would take the place of the former or of both.) These to be used in comparing other sources of unlike spectrum distribution by the use of tinted screens. The secondary standards to be compared with the primary standards of radiation and light.

(The advantage the acetylene standard has, according to the results so far obtained by me, lies principally in the fact that it can be set up anywhere, as a Clark cell can, without resource having to be had to one maker. Its less liability to disturbance from atmospheric conditions and its portability are also valuable, but I regard the question of obtaining a greater accuracy than $\frac{1}{2}$ per cent. by its means to be, while possible, of no importance, for the reasons given above.)

(In the reports a form of differential thermometer was mentioned as being used for comparison of radiations. This method has since been used by Weber and Toepler, but I have in later work found that a massive prism of copper having two thermocouples placed in holes bored in opposite sides of the copper

prism, one couple exposed to the standard, the other to the source to be measured, is better for my purpose. The copper prism is rotatable about a vertical axis, and is slid along the photometer bar till a galvanometer in the thermo circuit comes to zero. On account of the importance of having the black coating of the radiation standard and bolometer of the same nature and thickness it is believed that Lummer and Kurlbaum's method of blackening should be used, as referred to by Messrs. Nichols, Sharpe and Matthews.)

(It is obvious that if the sensation of light could be definitely proven to consist of the union of the sensations due to three different wave lengths, as in Maxwell's theory, it would only be necessary to determine the optical coefficients for these three wave lengths and their effect in modifying one another.)

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Contents of Vol. XIII., 1896, as far as Published.

Electric Elevators, with Details Descriptive of Recent Types. (Illustrated.) By Frank J. Sprague. (Abstract.) Address. Address Method of Supplying the Lines of Alternating Arc Lamps. (Illustrated.) By Prof. Elihu Thomson. Electric Lighting Experiments in Vacuum Tubes. (Illustrated.) By E. Goldstein. Electric Lighting Progress Abroad and at Niagara. May 20th, 1896. Standards of Light. Report of Sub-Committee. (Illustrated.) By Dr. Edward L. Nichols, C. H. Sharp and C. P. Matthews. No. 4, April.

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